
Pernyataan
sangkalan

EKOLOGI

Biogeochemical Cycle

Siti Nurleily Marliana

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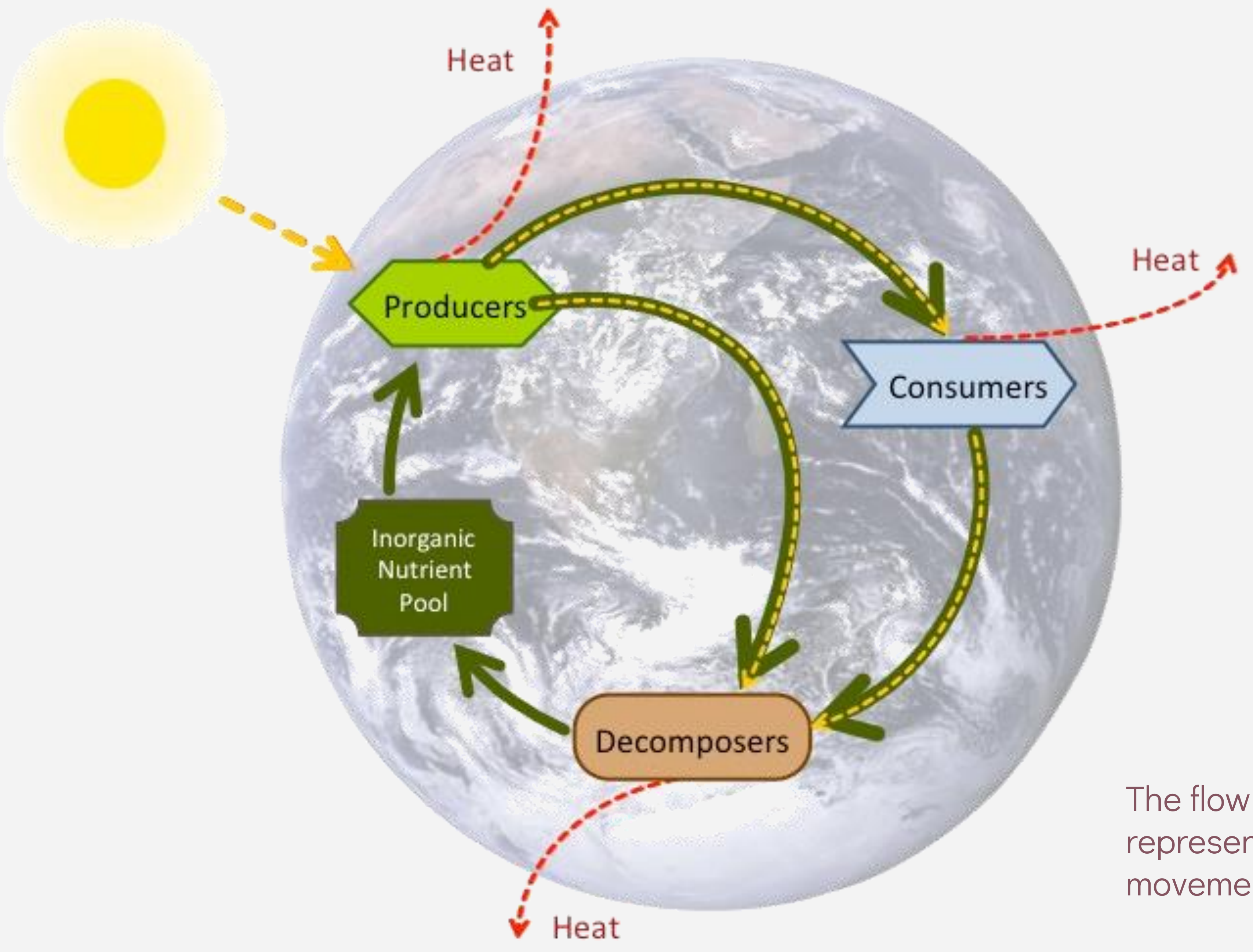
ENERGY FLUX & NUTRIENT CYCLING

ENERGY FLUX AND NUTRIENT CYCLING: THE RELATIONSHIPS



Energy flows directionally.

- Enter as sunlight or inorganic molecules (chemoautotrophs).
- Exit as heat.

However, the matter that makes up nutrients is recycled.

The flow of energy and the cycling of nutrients. The dark green lines represent the movement of nutrients and the dashed lines represent the movement of energy

ENERGY TRANSFORMATION IS LINKED WITH ELEMENT CYCLING

Organisms carry out the biochemical transformations, moving chemical elements through their cycles.

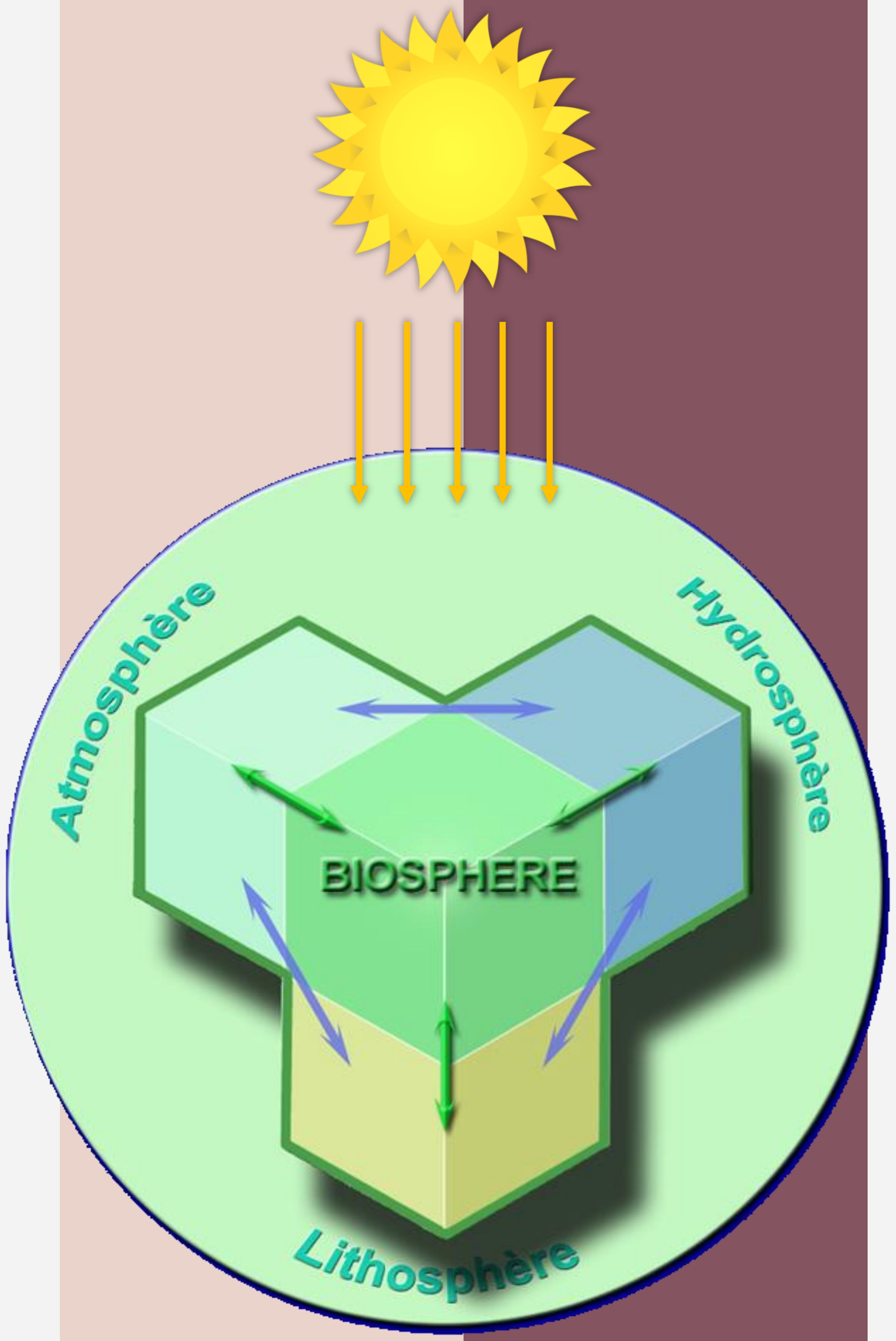
- Assimilation: transformations that incorporate inorganic forms of elements into the molecules of organisms
  - Dissimilation: transformation of organic carbon back to an inorganic form, accompanied by the release of energy

Chemical transformations can also occur outside organisms.

Geology and chemistry have major roles in the process.

- Hence the recycling of inorganic matter is called a biogeochemical cycle.

BIOGEOCHEMICAL CYCLES & EARTH SYSTEM



[Interface of spheres], Lamiot, via Wikimedia Commons, CC BY-SA 3.0.

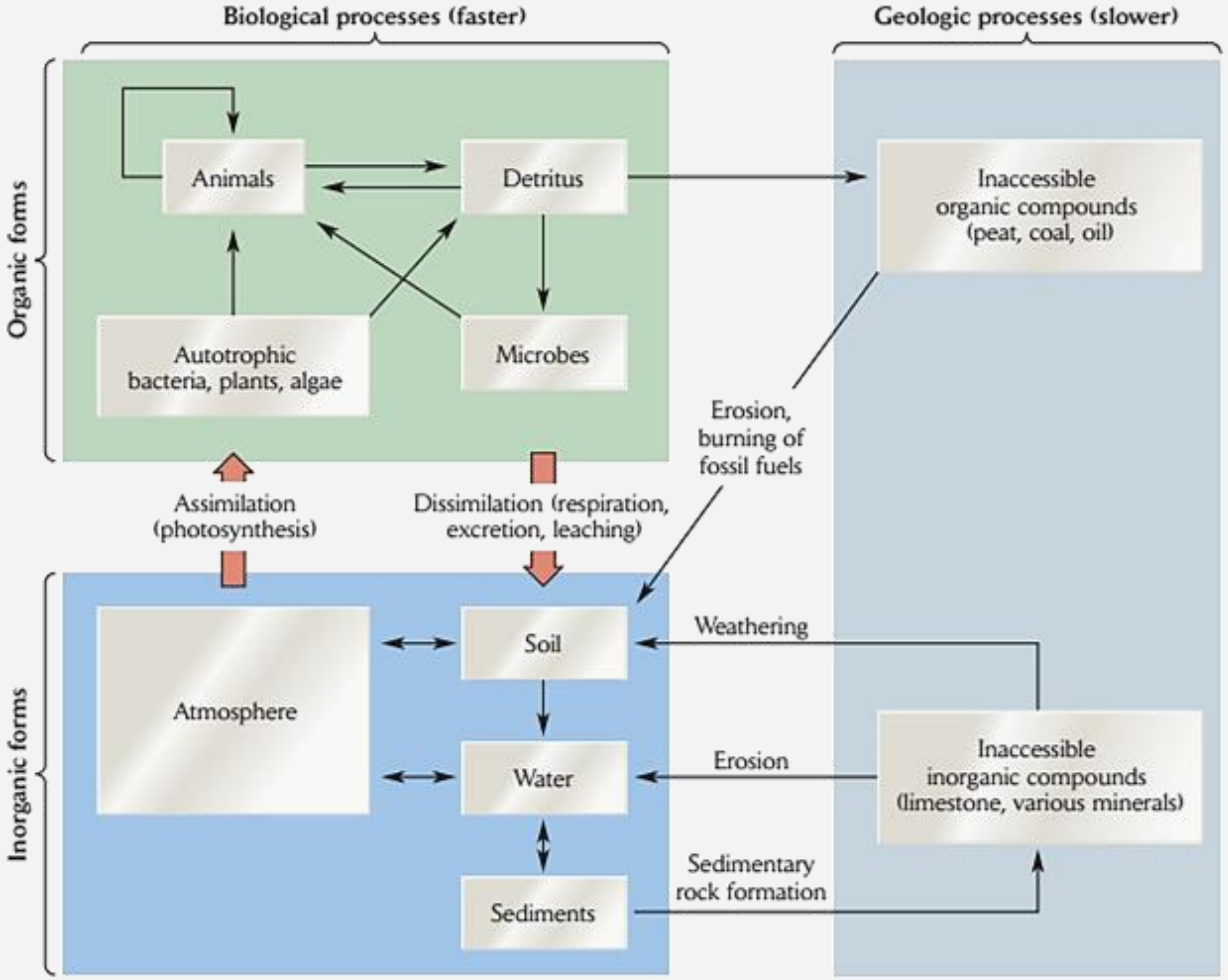
Biogeochemical cycles: the chemical interactions between the four -spheres.

Driven by the abiotic (physico-chemical) and biotic processes.

The elements cycle in either a **gas** cycle or a **sedimentary** cycle.

- In a **gas** cycle, elements move through the atmosphere.
- In a **sedimentary** cycle, elements move from land to water to sediment.

THE MODEL OF ELEMENTS CYCLING THROUGH ECOSYSTEMS



Ecosystems can be modeled as a series of linked compartments.

The cycling of elements through ecosystems modeled as a set of compartments. Within each compartment (e.g. elements in organic forms), there are subcompartments (animals, detritus, autotrophs, microbes).

[Figure 23.3], Ricklefs, 2008, The Economy of Nature. 6th ed. NY: W. H. Freeman and Company. Used under a Fair Use rationale.

NUTRIENT BUDGETS

Nutrients are gained and lost by ecosystems in a variety of ways.

The budget may be:

- More or less in balance.
- Inputs exceed outputs (nutrient accumulates).
- Outputs may exceed inputs (nutrients loss).

THE KEY BIOGEOCHEMICAL CYCLES

Water (H & O)

Essential for living organisms; makes up a major part of the body.

Carbon

A component of organic macromolecules and fossil fuels.

Nitrogen

A key part of nucleic acids & proteins. Important ingredient of artificial fertilizers.

Phosphorus

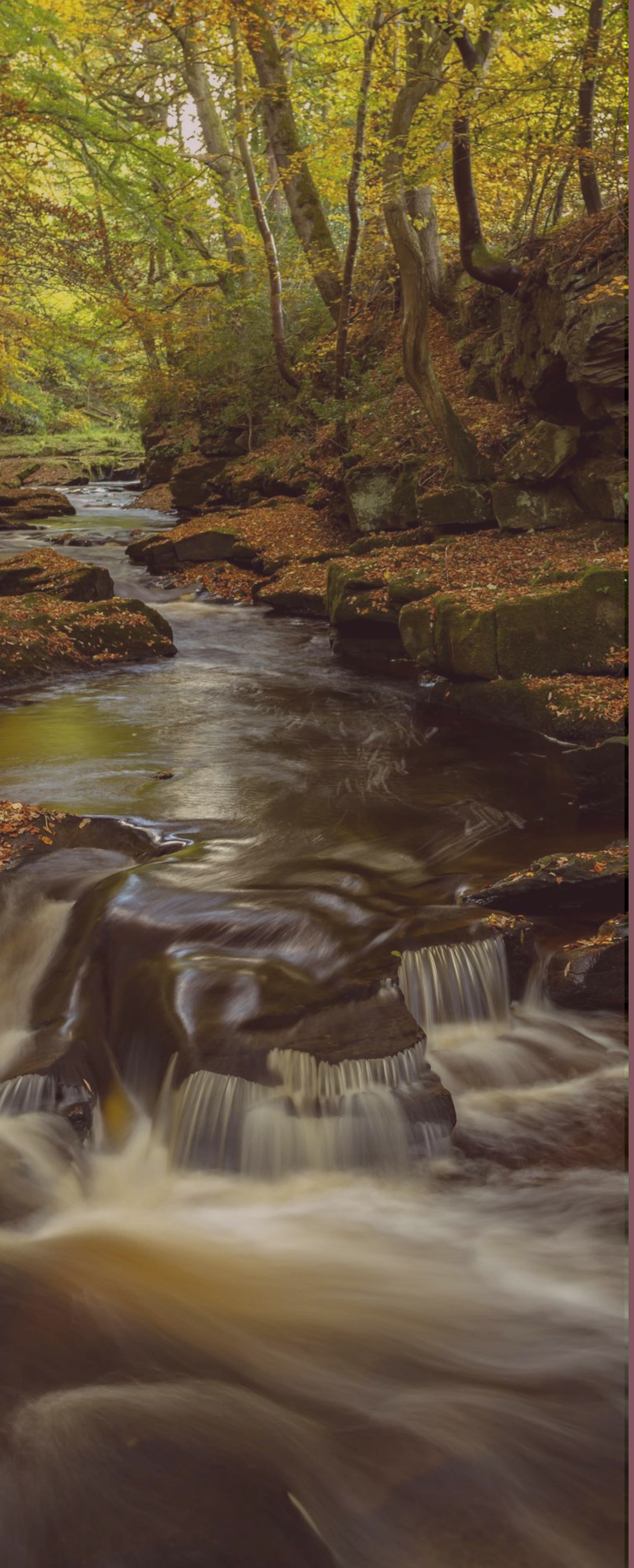
A key part of nucleic acids, cell membranes, and bones.

Sulfur

A key part of protein structure. A component of fossil fuels.

Oxygen

Important in cellular respiration, transforming food into energy.



COMPONENTS OF EACH ELEMENT CYCLE

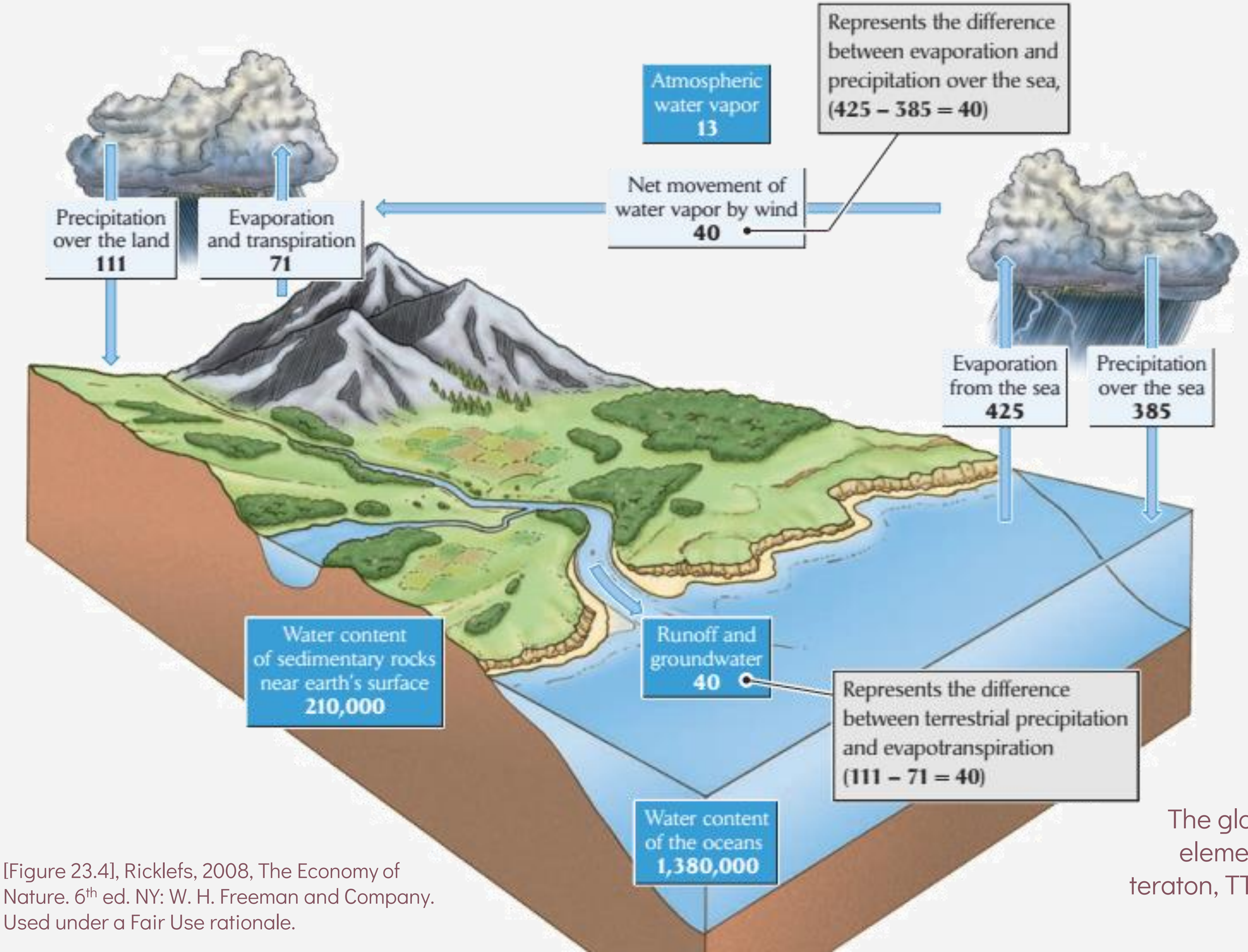
Three components:

1. "Pools" or reservoirs;
2. Fluxes in and out of pools;
3. Chemical or biochemical transformations.

Transformations are important; can lead to positive & negative consequences.

HYDROLOGIC CYCLE

GLOBAL HYDROLOGIC CYCLE



[Figure 23.4], Ricklefs, 2008, The Economy of Nature. 6th ed. NY: W. H. Freeman and Company. Used under a Fair Use rationale.

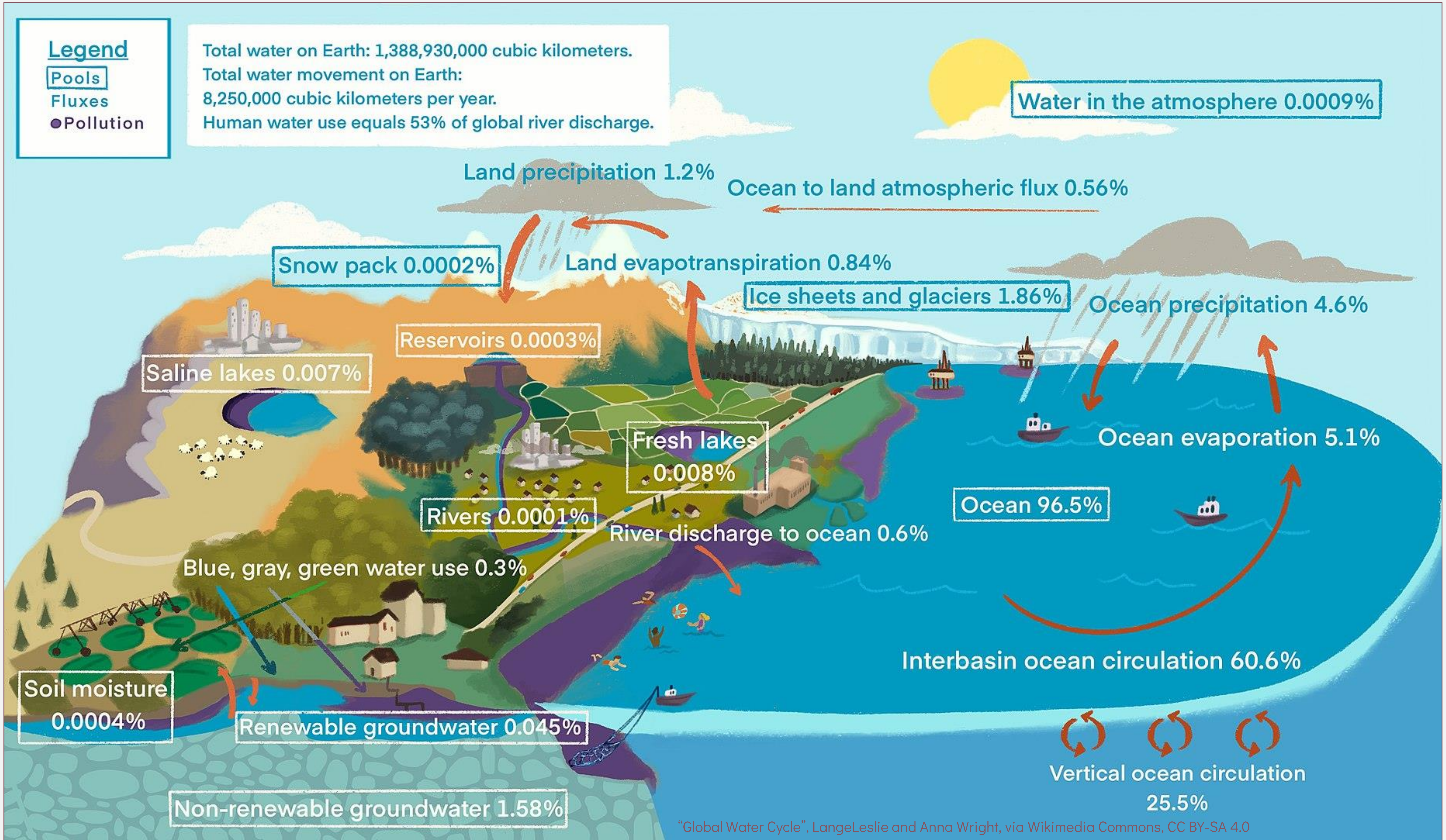
RESERVOIR – oceans, air (as water vapor), groundwater, lakes and glaciers; evaporation, wind and precipitation (rain) move water from oceans to land.

ASSIMILATION – plants absorb water from the ground, animals drink water or eat other organisms which are composed mostly of water.

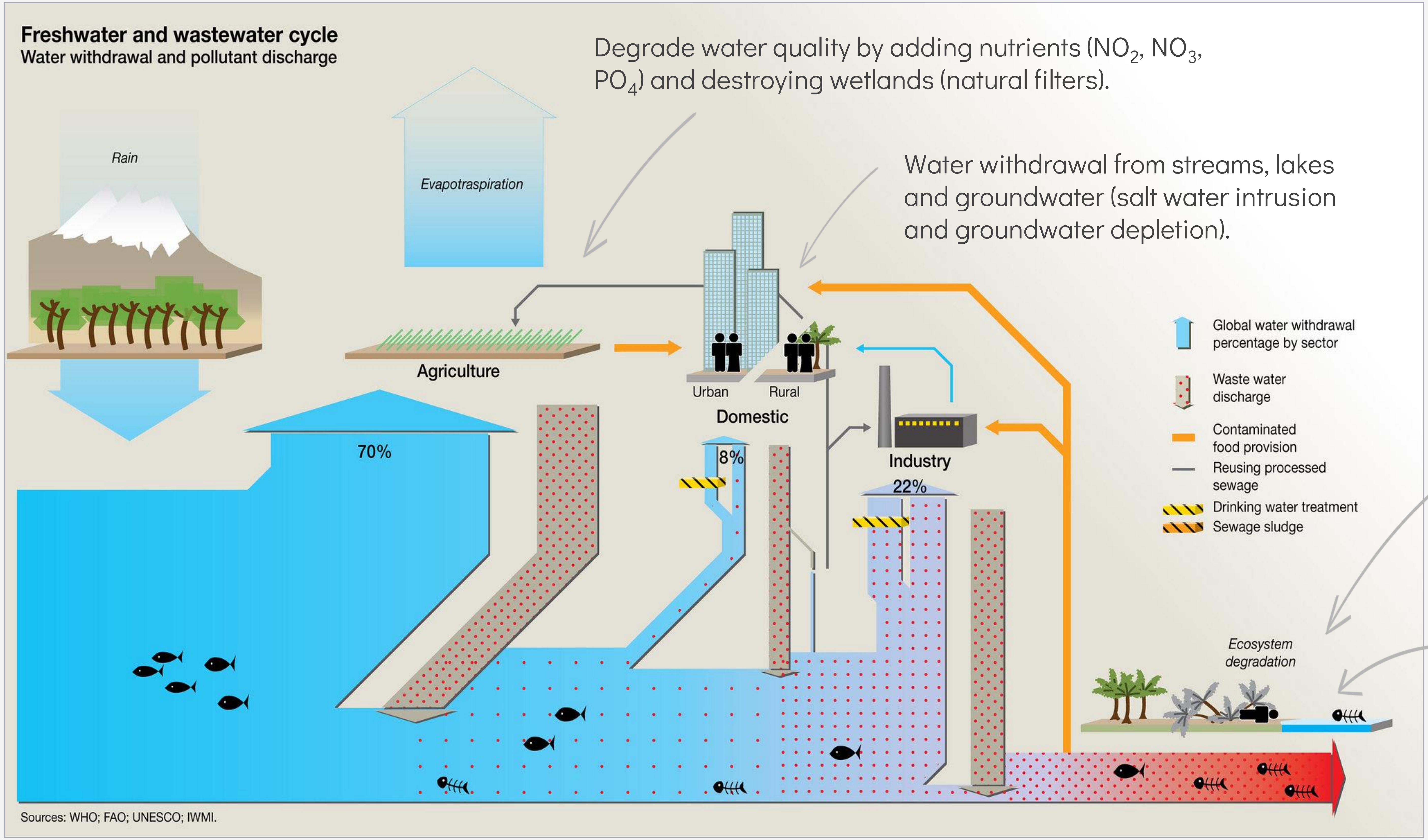
RELEASE – plants transpire, animals breathe and expel liquid wastes.

The global hydrologic cycle is analogous to the cycle of chemical elements. Dark boxes = the estimated sizes of compartments (in teraton, TT); light boxes = transfer between compartments (TT/year).

THE GLOBAL HUMAN-INTEGRATED WATER CYCLE



HUMAN IMPACTS TO WATER CYCLE



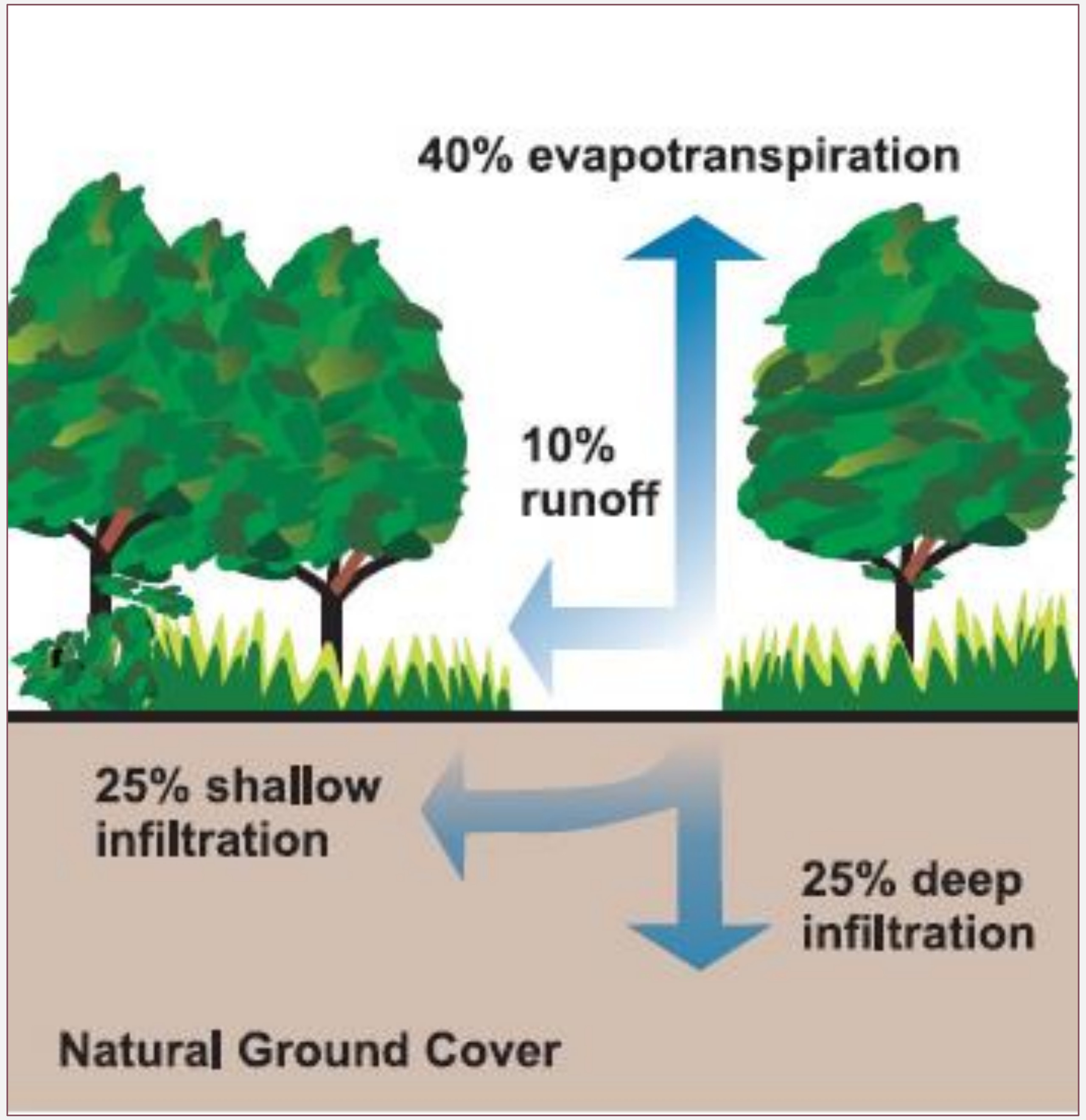
Degrade water quality by adding nutrients (NO_2, NO_3, PO_4) and destroying wetlands (natural filters).

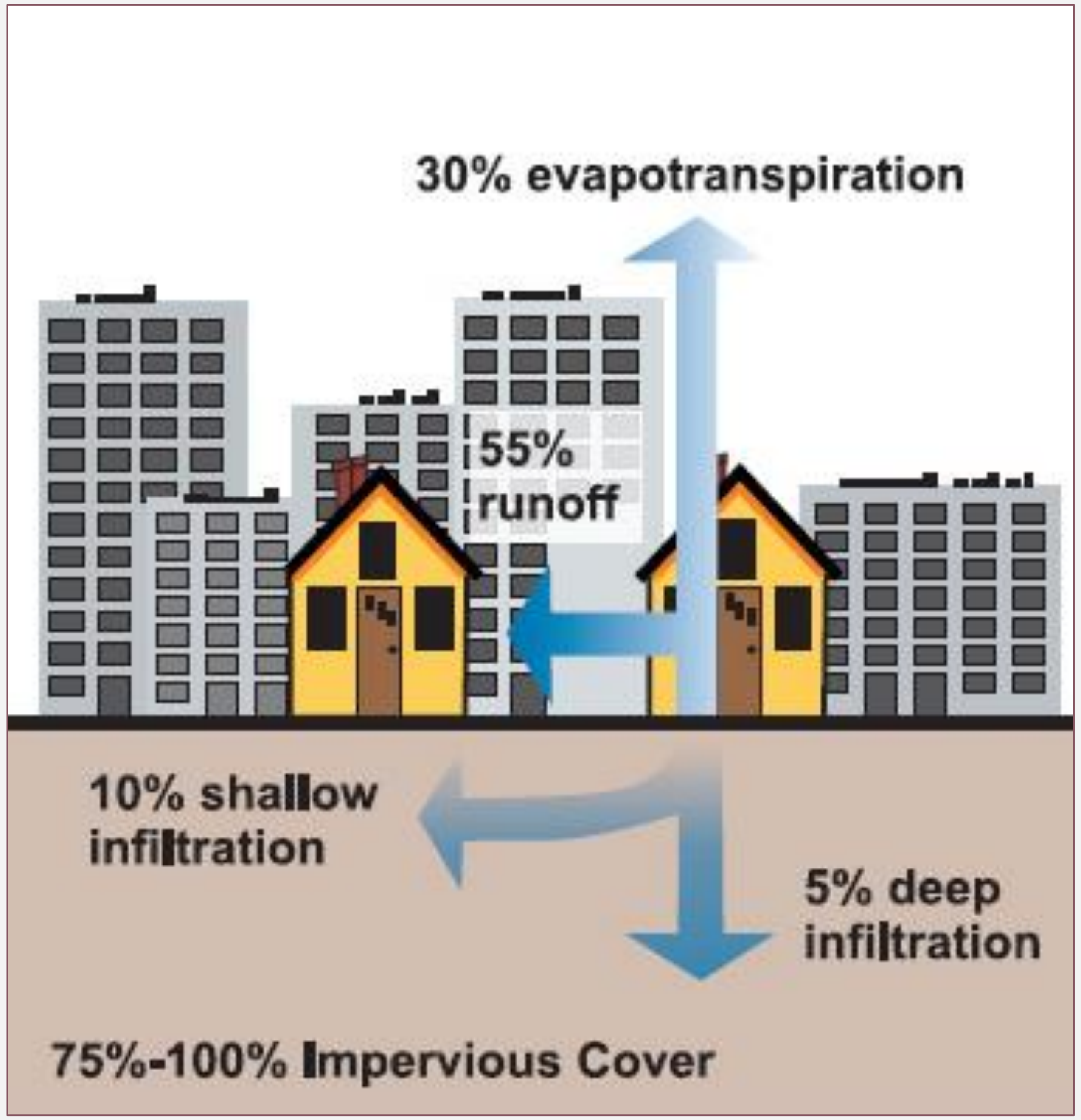
Water withdrawal from streams, lakes and groundwater (salt water intrusion and groundwater depletion).

Deforestation for agriculture, mining, road and building construction (nonpoint source runoff carrying pollutants and reduced recharge of groundwater).

Degrade water clarity by clearing vegetation and increasing soil erosion.

HUMAN IMPACTS TO WATER CYCLE





US Environmental Protection Agency, via Wikimedia Commons, Public Domain

CARBON CYCLE

IMPORTANCE OF CARBON CYCLE

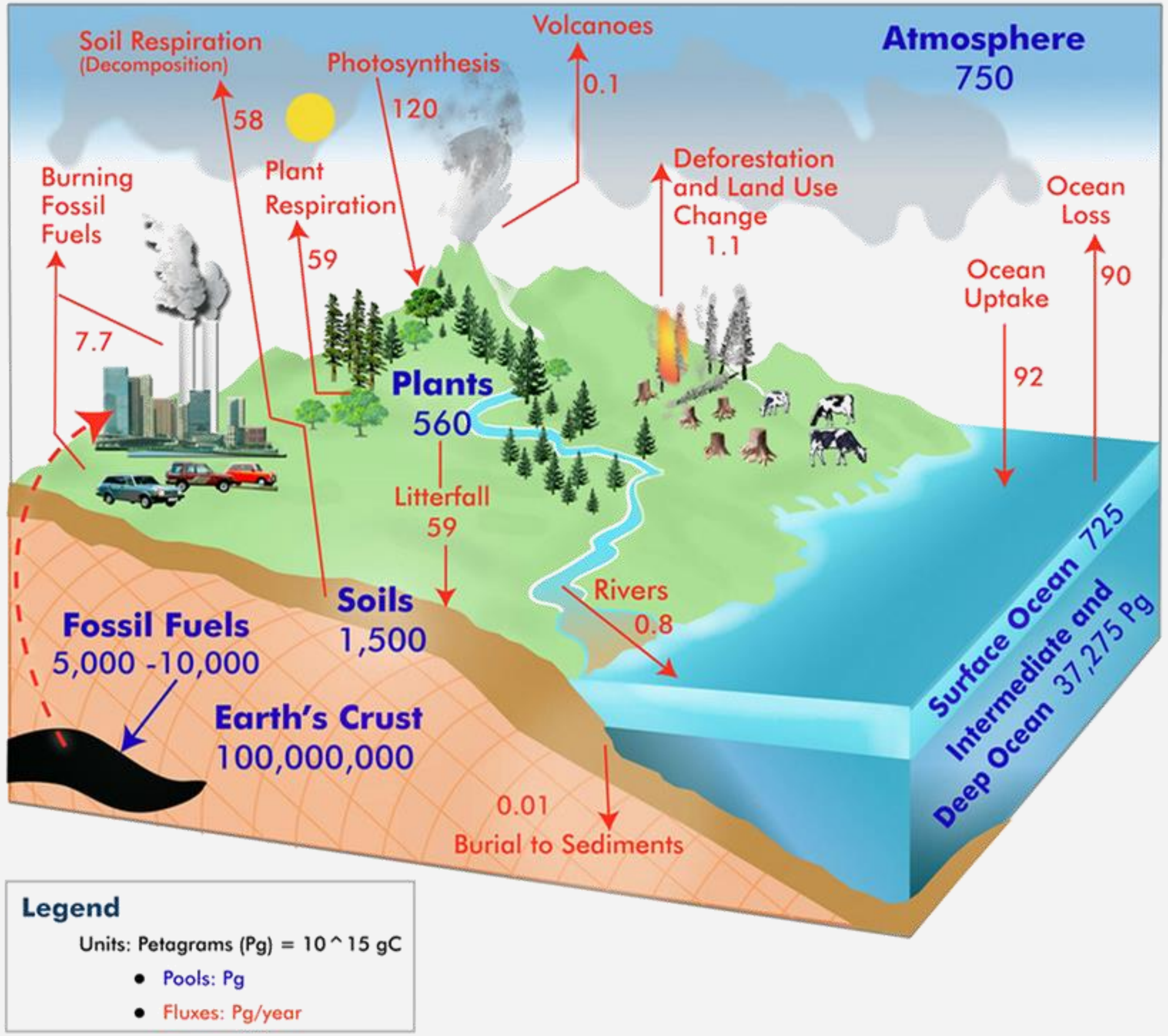
Carbon is the backbone of life.

- Required for building organic compounds.

Carbon is an energy source.

- Makes up the fossil fuels that are used today as energy sources.
- Also the cause of a major global environmental concern (CO_2).

CARBON FLUXES AND POOLS

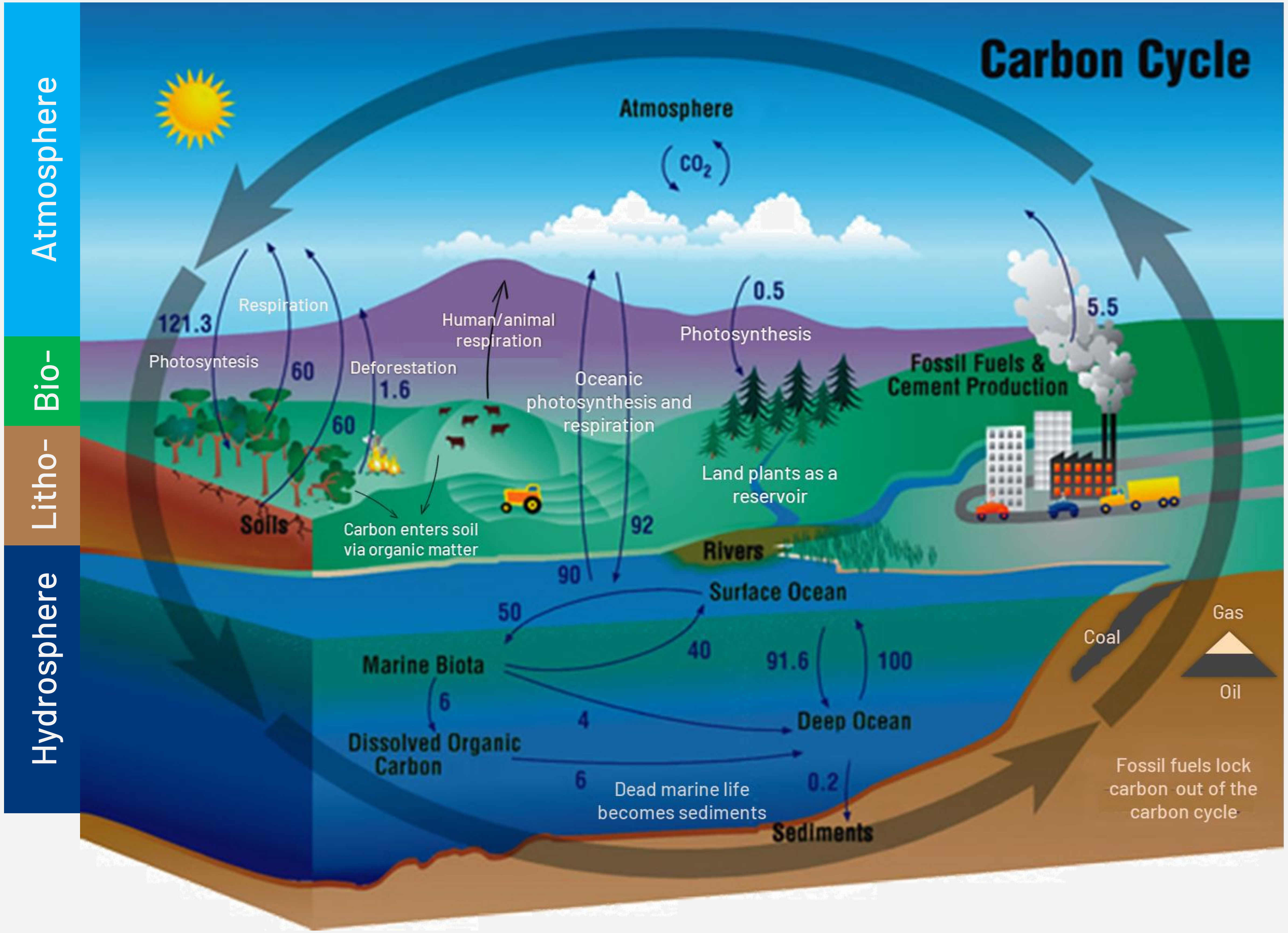


RESERVOIR – atmosphere (as CO_2), fossil fuels (oil, coal), durable organic materials (for example: cellulose).

ASSIMILATION – plants use CO_2 in photosynthesis; animals consume plants.

RELEASE – plants and animals release CO_2 through respiration and decomposition; CO_2 is released as wood and fossil fuels are burned.

GLOBAL CARBON CYCLE



Two interconnected carbon subcycles:

Biological carbon cycle

Rapid carbon exchange among living organisms.

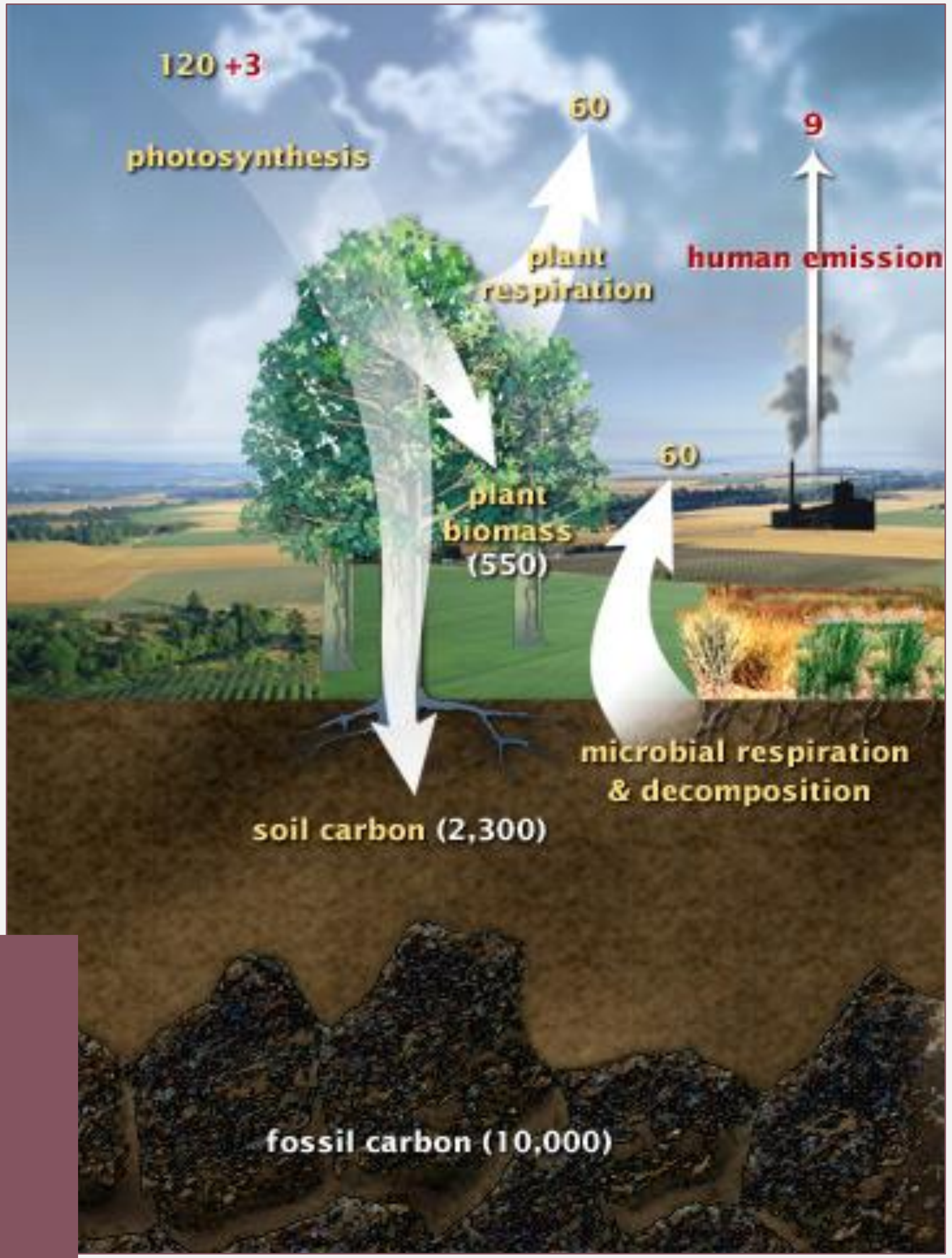
Geological carbon cycle

Long-term cycling of carbon through geologic processes.

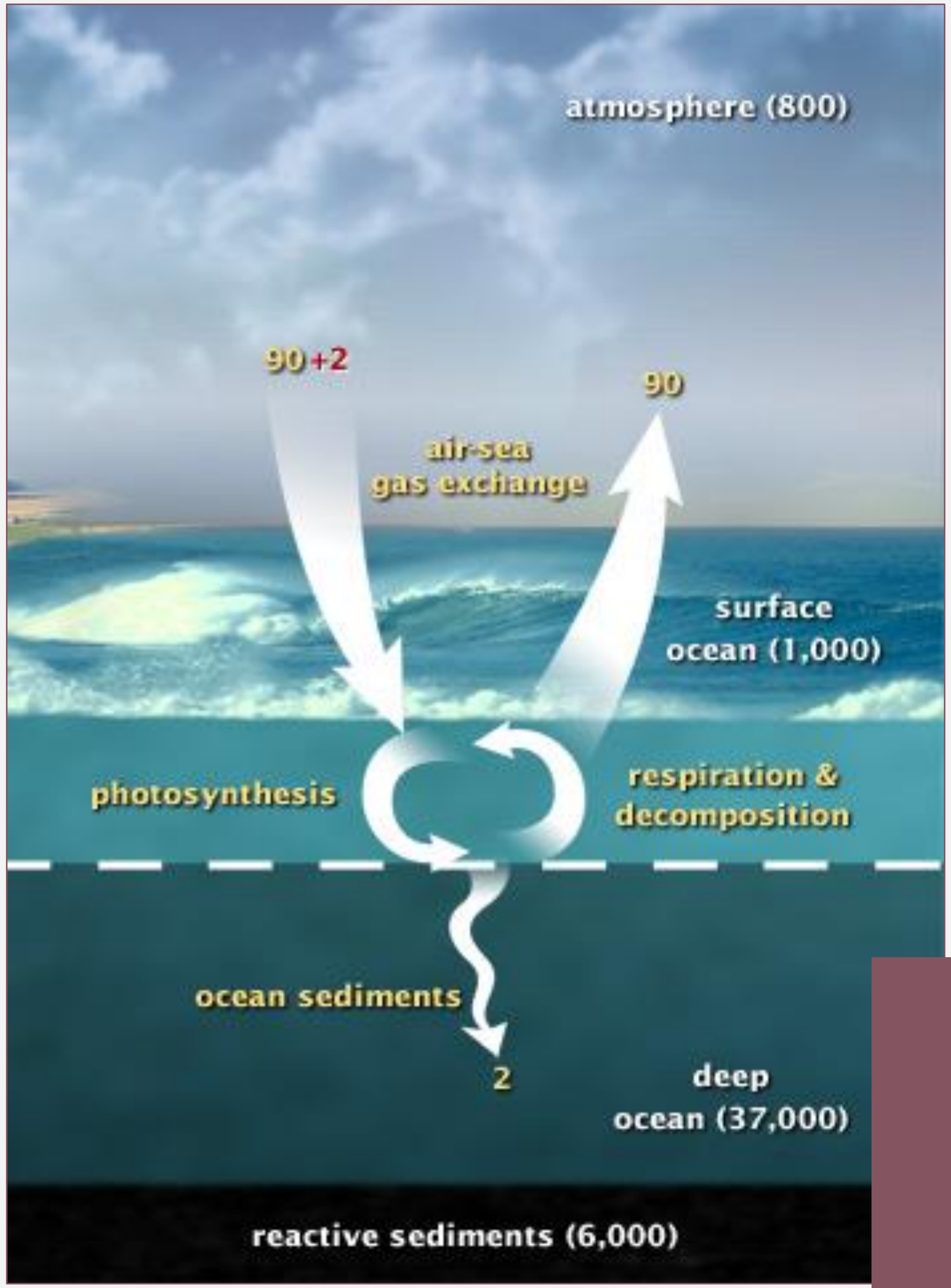
The annual flux of CO_2 in GigaTons (Gt) between each of the Earth's reservoirs (as both a sink and a source). Data from 2003.

MARINE & TERRESTRIAL CARBON CYCLE

TERRESTRIAL CARBON CYCLE



MARINE CARBON CYCLE



SOURCES OF CARBON

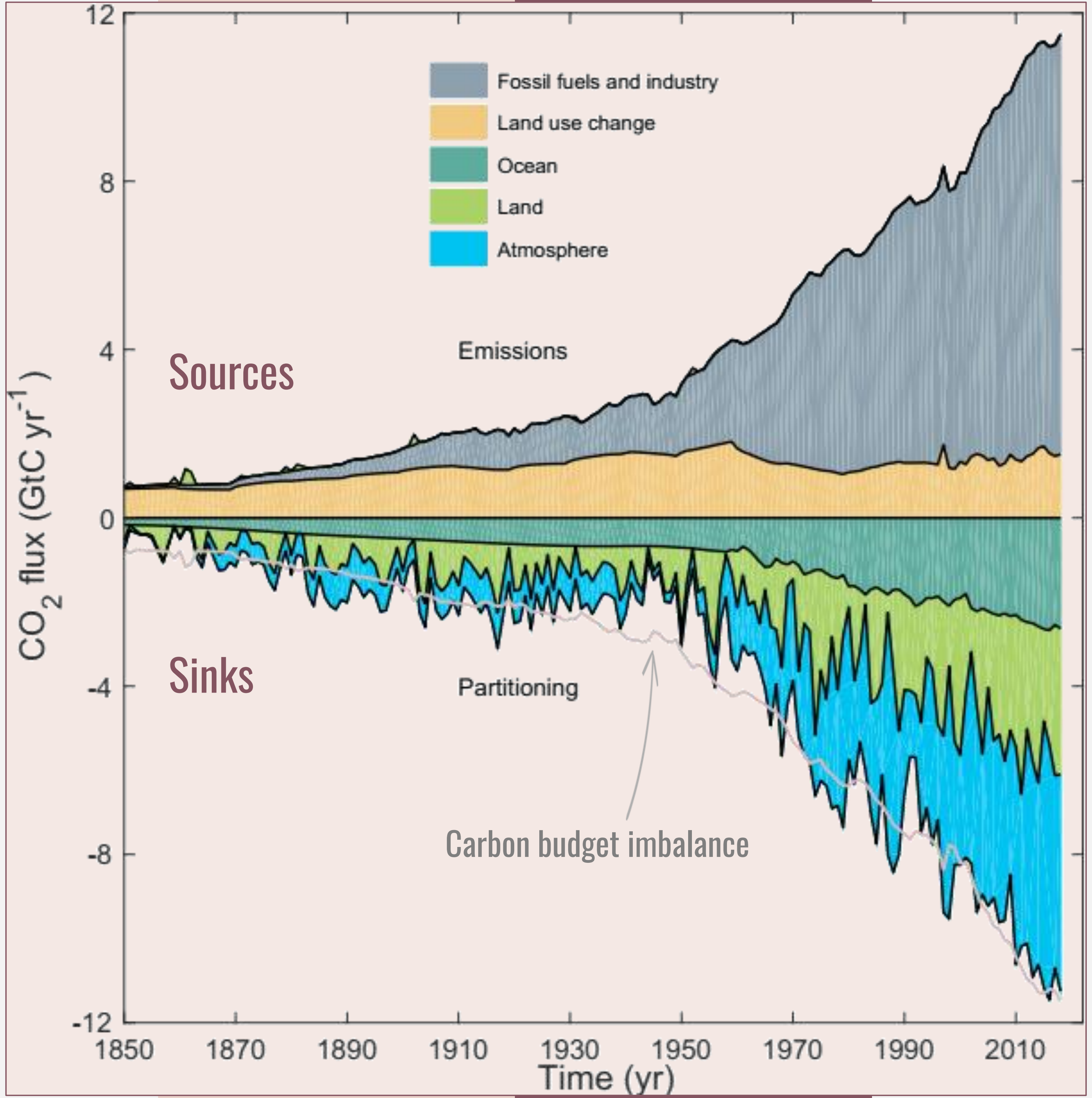
Natural sources

- Dead organisms
- Animal waste
- Atmospheric CO_2
- Weathering
- Methane gas from ruminants
- Aerobic respiration

Anthropogenic sources

- Burning wood or forests
- Vehicles: cars, trucks, planes, etc
- Fossil fuels burning

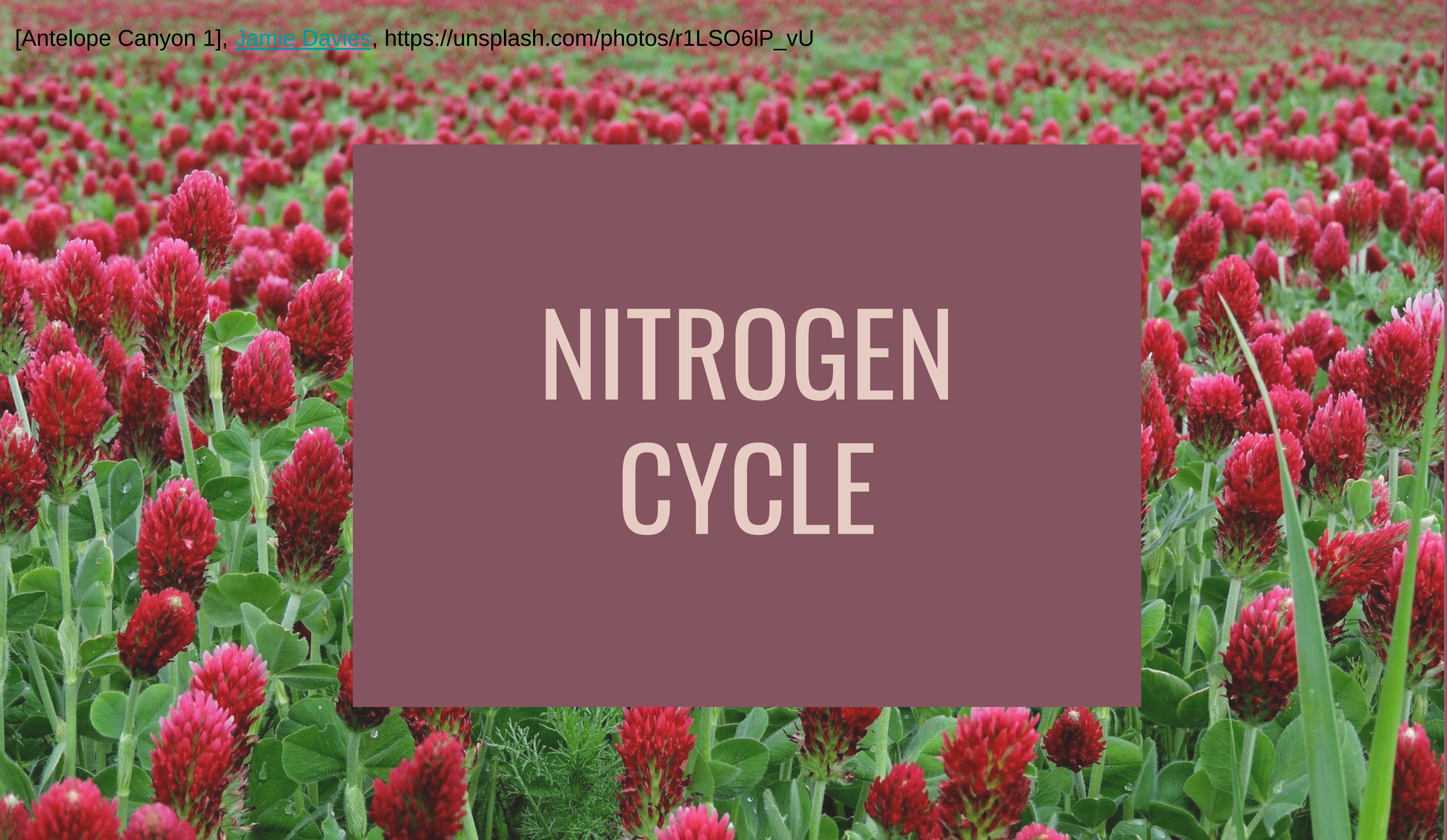
CARBON BUDGET IMBALANCE



Carbon fluxes of major anthropogenic sources (positive) and natural sinks (negative) demonstrate the corresponding increases in both from 1850 to 2017.

A **budget imbalance** is represented by the difference between the bottom pink line (reflecting total emissions) and the sum sinks.

[Antelope Canyon 1], Jamie Davies, https://unsplash.com/photos/r1LSO6lP_vU



NITROGEN CYCLE

NITROGEN FACTS


“Nitrogen-fixing nodules in legumes”, Terraprima, via Wikimedia Commons, CC BY-SA 3.0.

The most abundant gas in the atmosphere.

An essential constituent of protein, DNA, RNA, and chlorophyll.

Is often the most limiting nutrient in soil and water.

Must be fixed/converted into a usable form for organisms.

FORMS OF NITROGEN

ATMOSPHERIC DINITROGEN
N_2

AMMONIA
NH_3 (gas)

AMMONIUM
NH_4^+

NITRATE
NO_3

NITRITE
NO_2

UREA
$CO(NH_2)_2$

ORGANIC N

MINERALIZATION

Organic nitrogen (many forms) → Inorganic nitrogen (ammonium)

Organic nitrogen (many forms) ← Inorganic nitrogen (ammonium & nitrate)

IMMOBILIZATION

Mineralization and **immobilization** is a **reversed** process in nitrogen transformation

Diagram is adapted from "Figure 1. Mineralization and immobilization processes", Killpack & Buchholz, https://extension.missouri.edu/publications/wq260, used under a Fair Use rationale.

SOURCES OF NITROGEN

Natural & anthropogenic sources:

- Lightning
- Nitrogen fixation
- Animal residues
- Organic fertilizers
- Inorganic fertilizers
- Crop/agricultural residues

Two pathways into ecosystem:

- Atmospheric deposition
- Nitrogen fixation

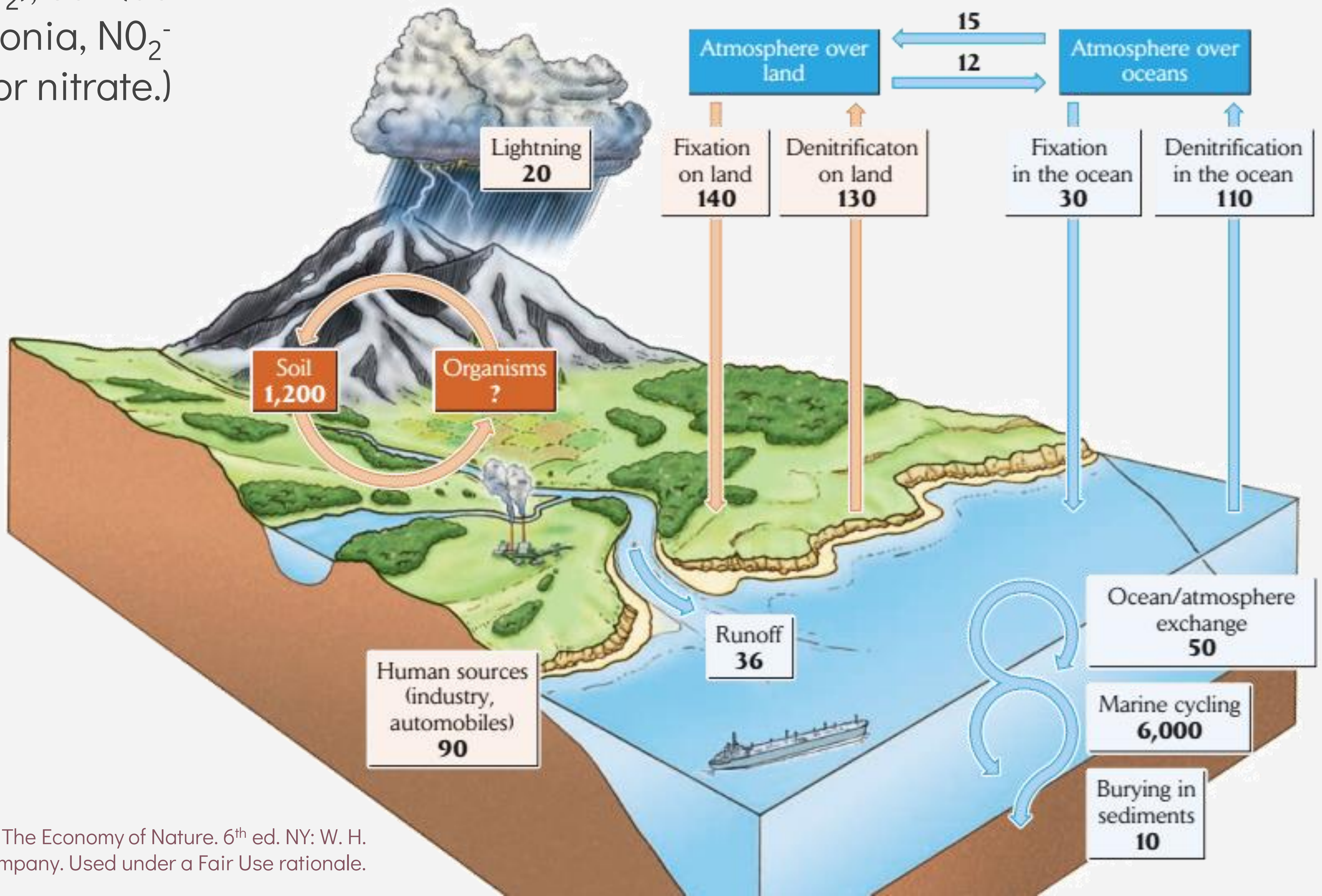
GLOBAL NITROGEN CYCLE

RESERVOIR – atmosphere (as N_2); soil (as NH_4^+ or ammonium, NH_3 or ammonia, NO_2^- or nitrite, NO_3^- or nitrate.)

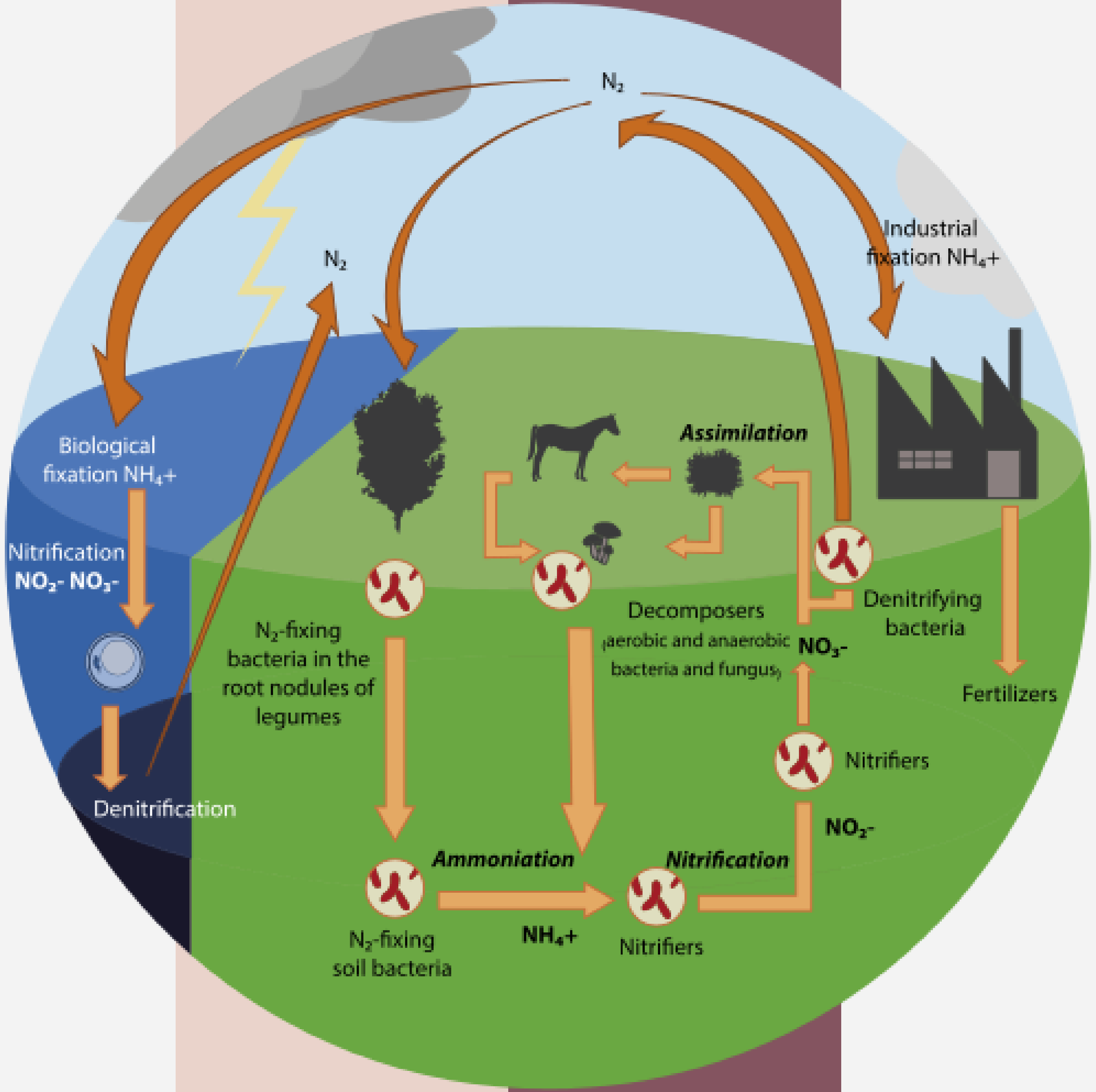
ASSIMILATION – plants absorb nitrogen as either NH_4^+ or as NO_3^-, animals obtain nitrogen by eating plants and other animals (see stages in nitrogen assimilation).

RELEASE – denitrification by denitrifying bacteria; ammonification by detritivorous bacteria; animals excrete NH_4^+ (or NH_3), urea, or uric acid.

Pools/reservoirs = dark boxes
Fluxes & transformations = light boxes & arrows

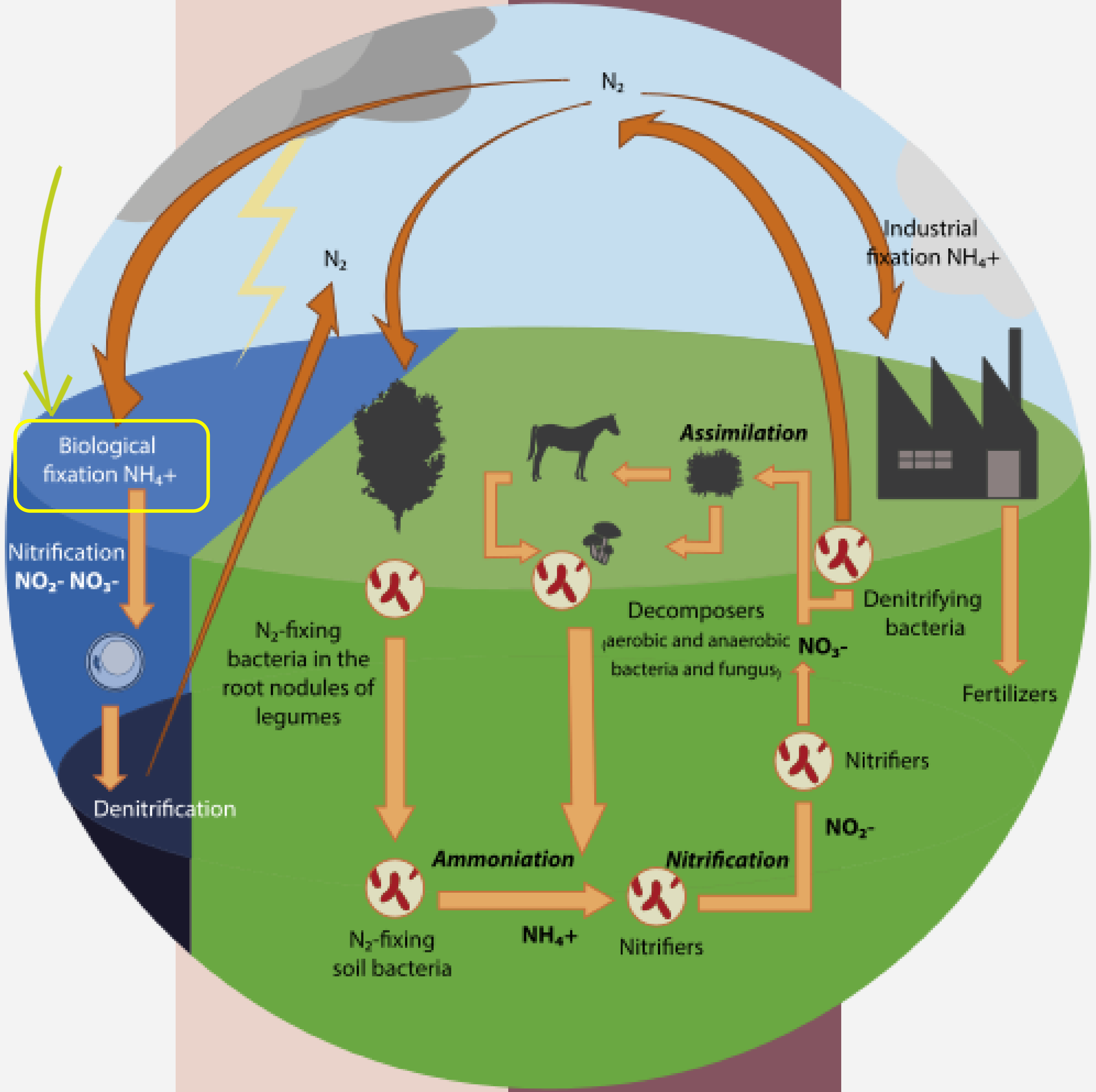


[Figure 23.11], Ricklefs, 2008, The Economy of Nature. 6th ed. NY: W. H. Freeman and Company. Used under a Fair Use rationale.



TRANSFORMATIONS OF NITROGEN

1. Nitrogen fixation
2. Nitrification
3. Assimilation
4. Ammonification/ mineralization
5. Denitrification



"Nitrogen cycle", Eme Chicano, via Wikimedia Commons, CC0.

TRANSFORMATIONS OF NITROGEN
1. NITROGEN FIXATION

Conversion of N_2 into biologically available nitrogen.

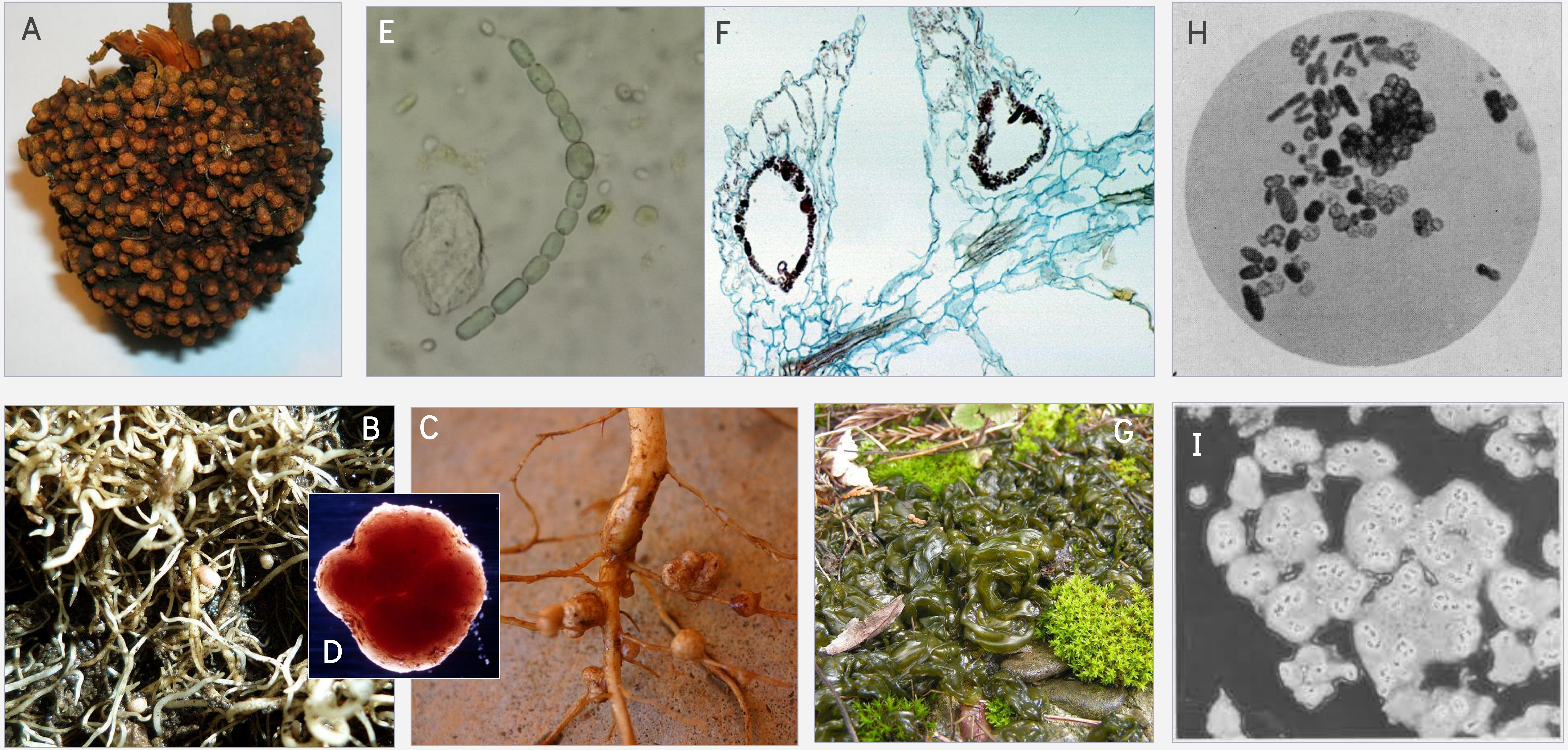
- High-energy fixation
- **Biological fixation**

$$N_2\ (g) + 8\ H^+ + 8\ e^- \rightarrow 2\ NH_3(g) + H_2\ (g)$$

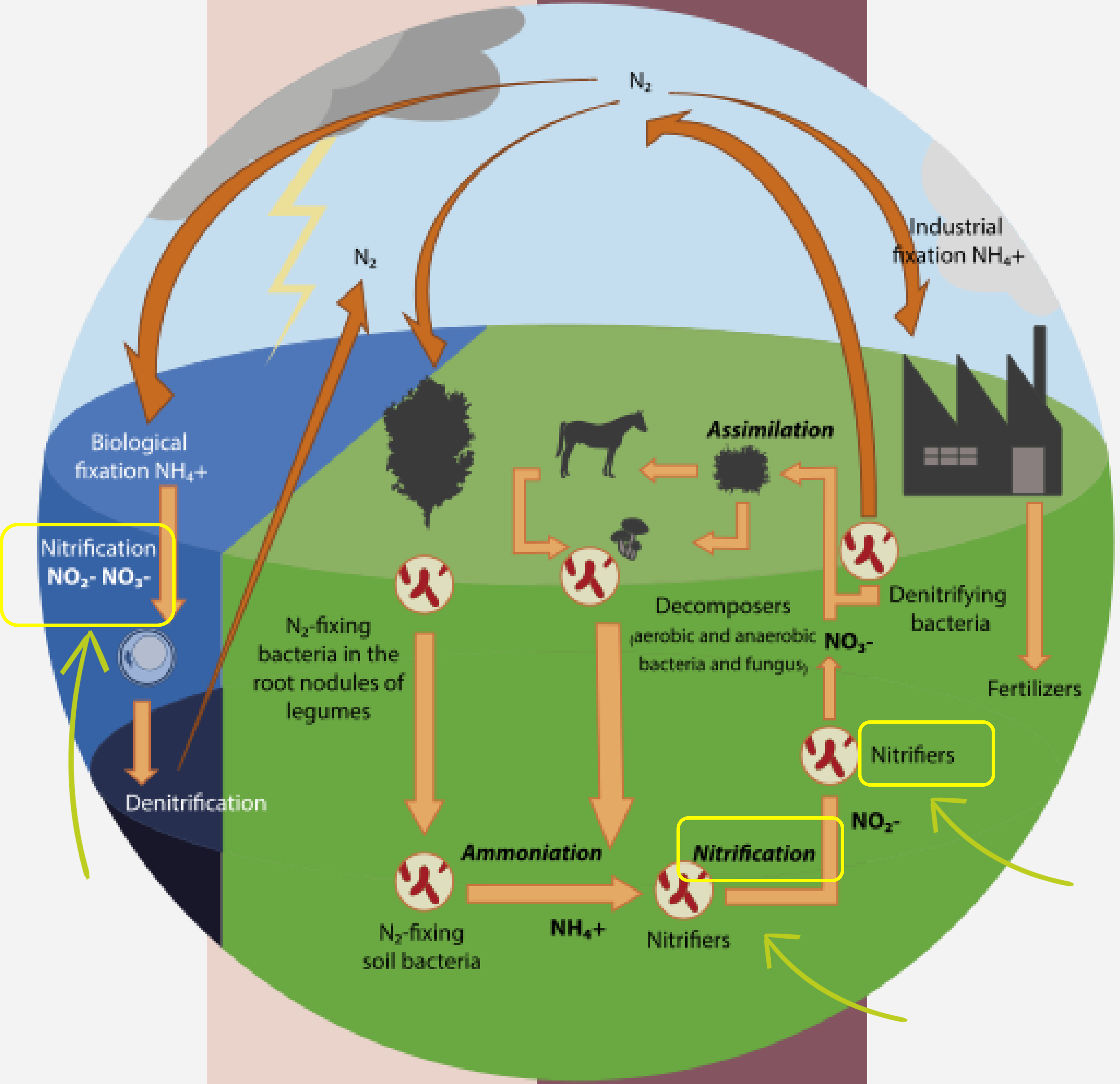
Organisms performing biological fixation:

- Symbiotic bacteria
- Non-symbiotic organisms (free-living aerobic bacteria & cyanobacteria

NITROGEN-FIXING ORGANISMS



A to F: Symbiotic nitrogen-fixing associations, (A) *Frankia* in alder root nodule gall; (B) *Trifolium repens* root nodules; (C) *Vigna unguiculata* root nodules; both (B) and (C) in symbiosis with (D) *Rhizobium* bacteria; (E) Cyanobacteria *Anabaena azollae*, the symbiont of (F) *Azolla*, an aquatic fern (shown here as a longitudinal section with the cyanobacterium in leaf pockets). G to I: non-symbiotic, (G) *Nostoc commune,* (H) *Azotobacter*, (I) *Beijerinckia*.. Image credits at the end of presentation.



“Nitrogen cycle”, Eme Chicano, via Wikimedia Commons, CC0.

TRANSFORMATIONS OF NITROGEN
2. NITRIFICATION

Conversion of ammonia or ammonium to nitrite and nitrate.

Carried out by prokaryotes, mostly aerobically.

Two steps:

- **Nitritation**: oxidation of ammonia to nitrite.

$$2\ NH_4{}^{+} + 3\ O_2 \rightarrow 2\ NO_2{}^{-} + 4\ H^{+} + 2\ H_2O$$

- **Nitration**: oxidation of nitrite to nitrate using nitrite oxidoreductase (NOR) enzyme.

$$2\ NO_2{}^{-} + O_2 \rightarrow 2\ NO_3{}^{-}$$

ORGANISMS IN NITRIFICATION

Ammonia oxidizers (step 1)

Ammonia-oxidizing bacteria (AOB):
genera *Nitrosomonas*, *Nitrosospira*, and *Nitrosococcus*.

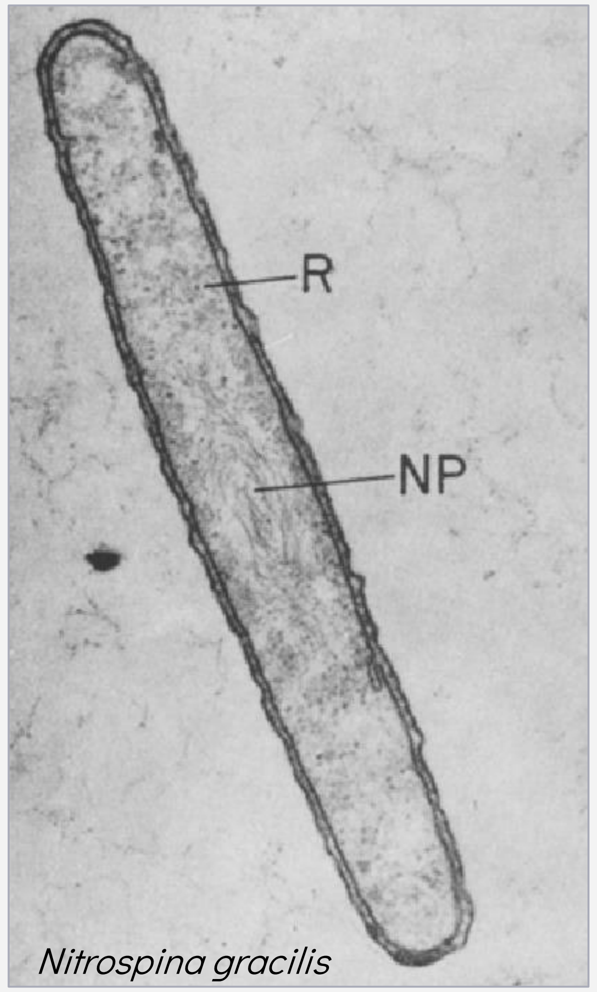
Ammonia-oxidizing archaea (AOA):
e.g. *Nitrosopumilus maritimus*, *Nitrososphaera gargensis**, *Nitrosotalea devanaterra**, *Nitrosoarchaeum limnia**.

* Zhou et al. 2015. Sci Rep 5, 15969. doi: 10.1038/srep15969

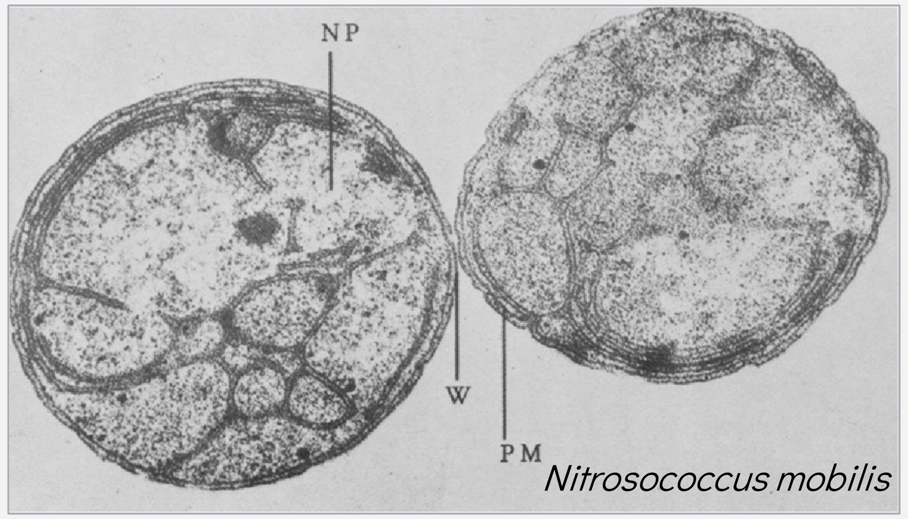
Nitrite oxidizers (step 2)

Nitrite-oxidizing bacteria (NOB):
genera *Nitrospira*, *Nitrobacter*, *Nitrococcus*, and *Nitrospina*.

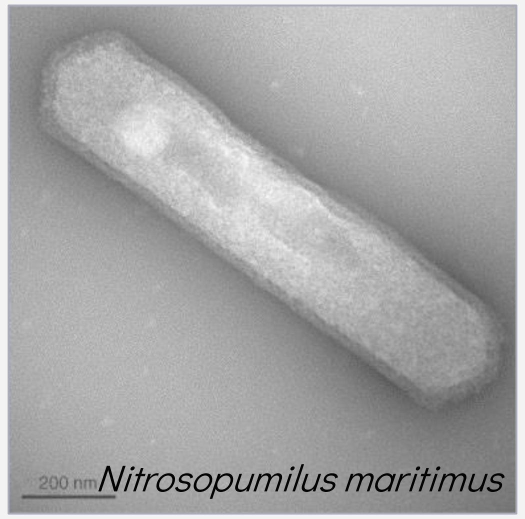

Nitrobacter winogradskyi



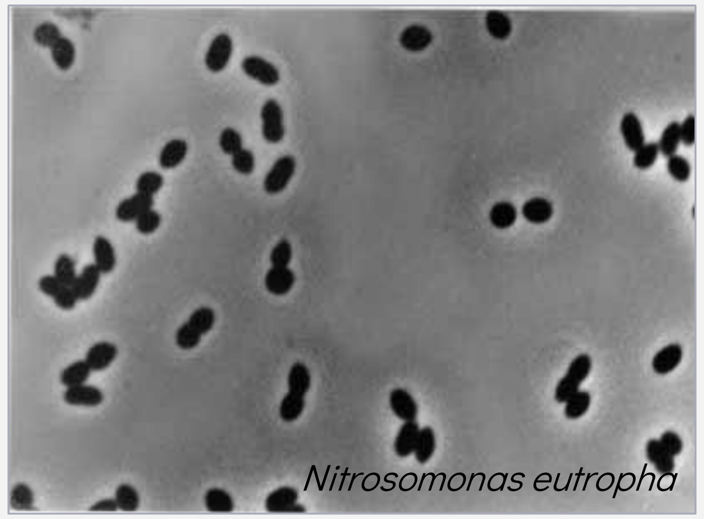
Nitrospina gracilis



Nitrosococcus mobilis



Nitrosopumilus maritimus


Nitrosomonas eutropha

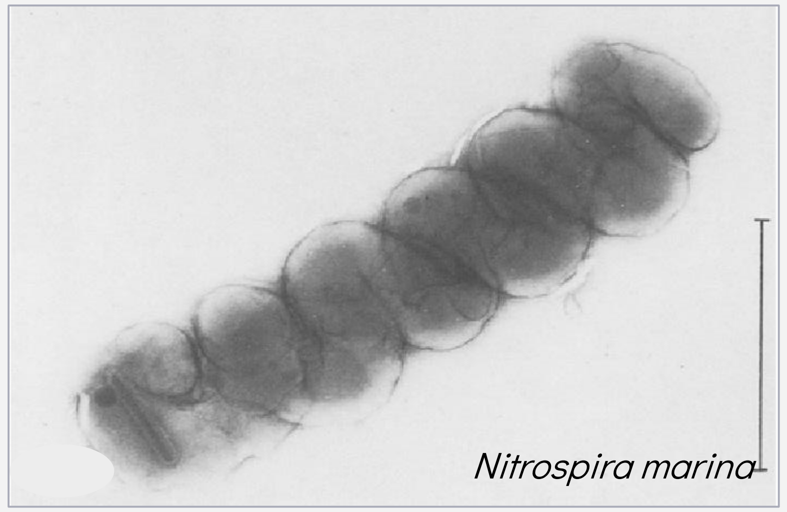
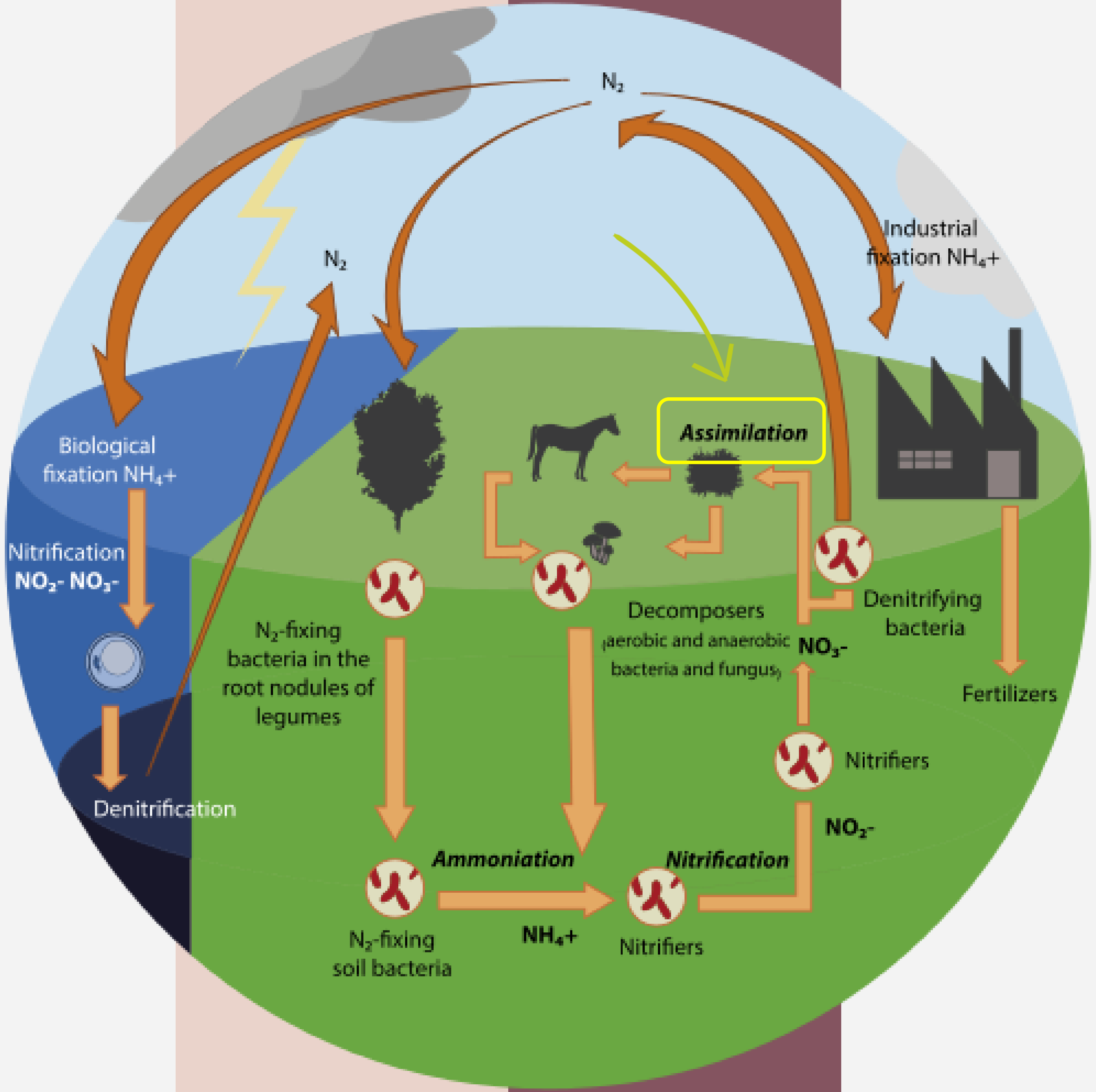

Nitrospira marina

Image credits at the end of presentation.



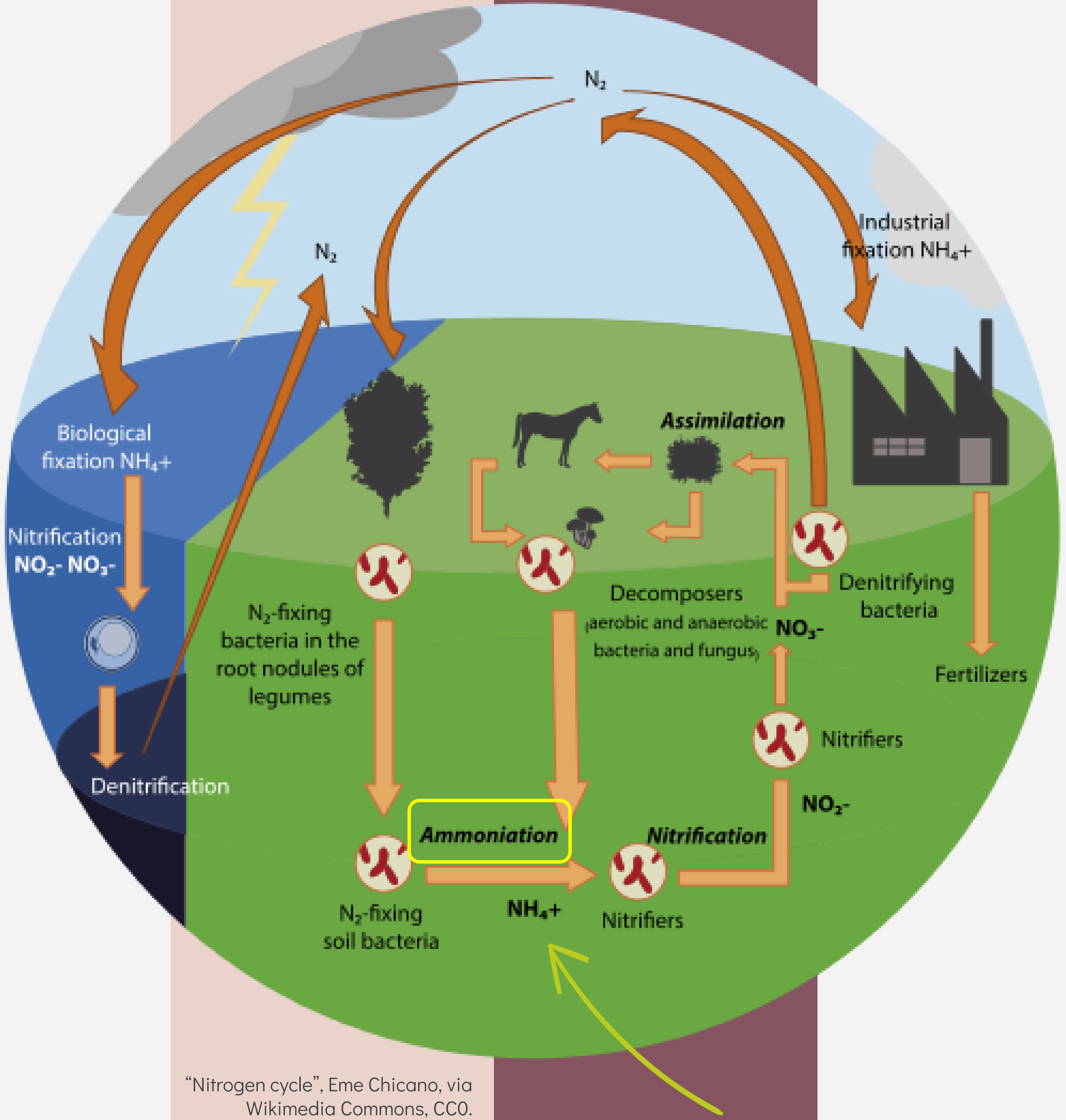
"Nitrogen cycle", Eme Chicano, via Wikimedia Commons, CC0.

TRANSFORMATIONS OF NITROGEN
3. ASSIMILATION

Incorporation of nitrate or ammonia into biological tissues.

Organisms that cannot fix N_2 depend on the ability to assimilate nitrate or ammonia for their needs.

- Plants take up nitrates through their roots and use them to make amino acids and nucleic acids.
- Animals that eat the plants converting them into their own body compounds.



"Nitrogen cycle", Eme Chicano, via Wikimedia Commons, CC0.

TRANSFORMATIONS OF NITROGEN

4. AMMONIFICATION

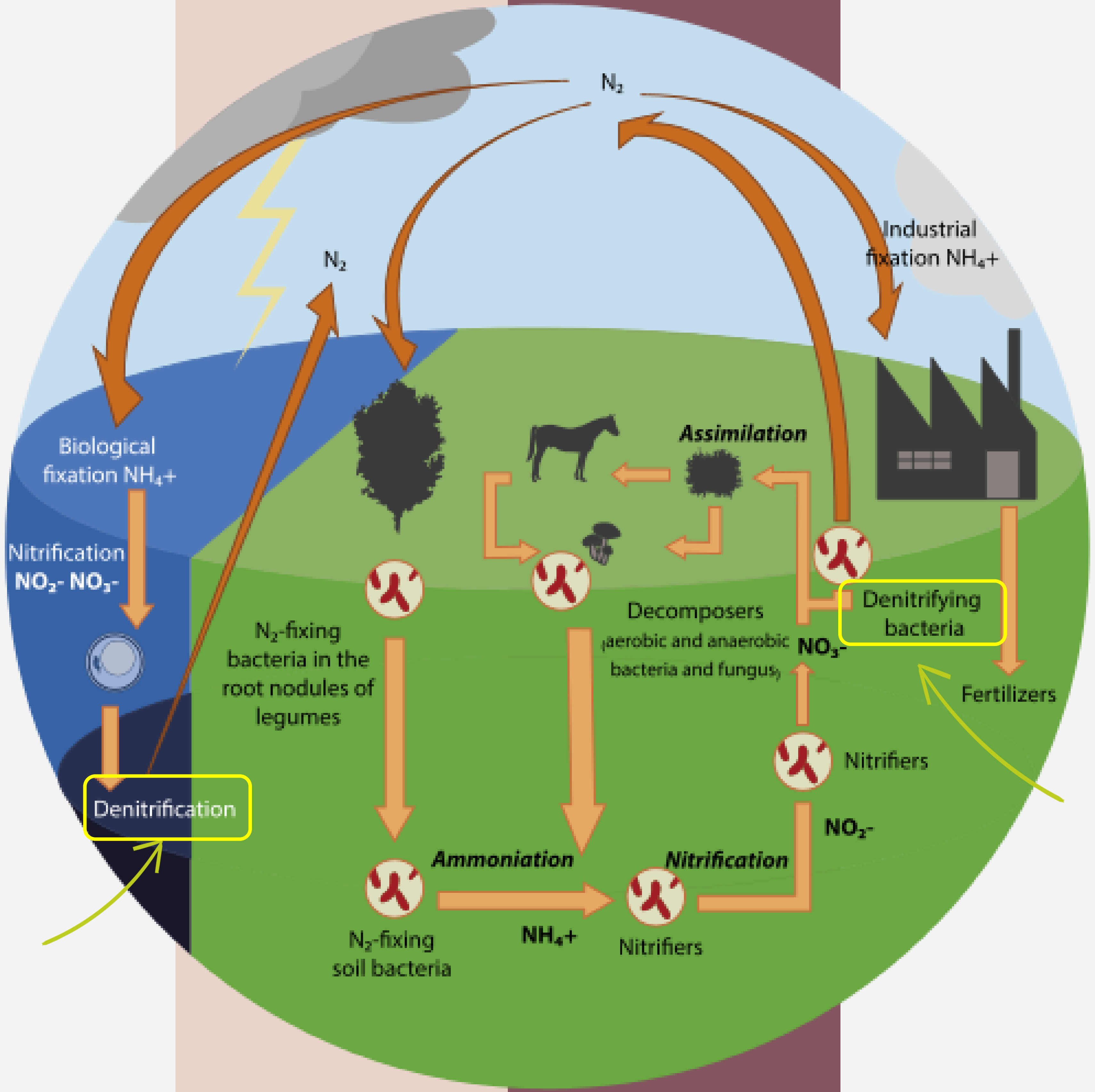
Conversion of organic nitrogen into inorganic ammonia or ammonium ions.

Decomposition (aerobic and anaerobic) by soil bacteria (e.g. *Bacillus*, *Clostridium*, *Proteus*, *Pseudomonas*, and *Streptomyces*) and fungi on dead plants and animals.

N-containing compounds are broken down into ammonia or ammonium.

$$NH_2{-}CO{-}NH_2 + H_2O\ (l) \rightarrow 2\ NH_3\ (g) + CO_2 (g)$$

TRANSFORMATIONS OF NITROGEN
5. DENITRIFICATION



"Nitrogen cycle", Eme Chicano, via Wikimedia Commons, CC0.

Conversion of nitrate to nitrogen gas, returning it to the atmosphere.

- Removing bioavailability.

An anaerobic process, occurring mostly in soils and sediments and anoxic zones in lakes and oceans.

Complete redox reaction of denitrification.

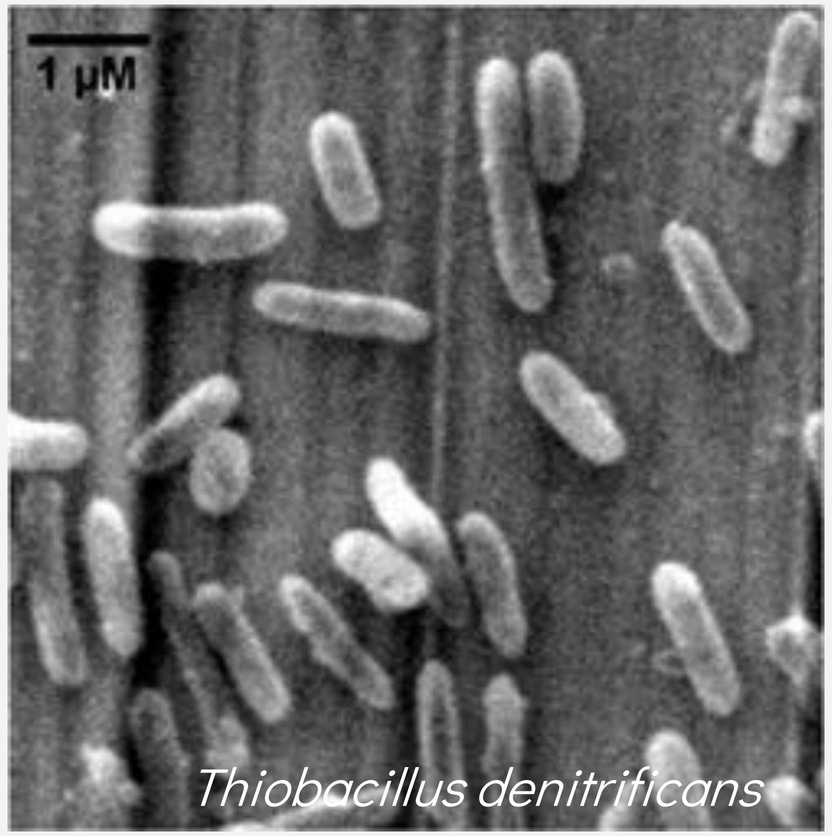
$$NO_3{}^- \rightarrow NO_2{}^- \rightarrow NO + \boldsymbol{N_2O} \rightarrow N_2$$

ORGANISMS IN DENITRIFICATION

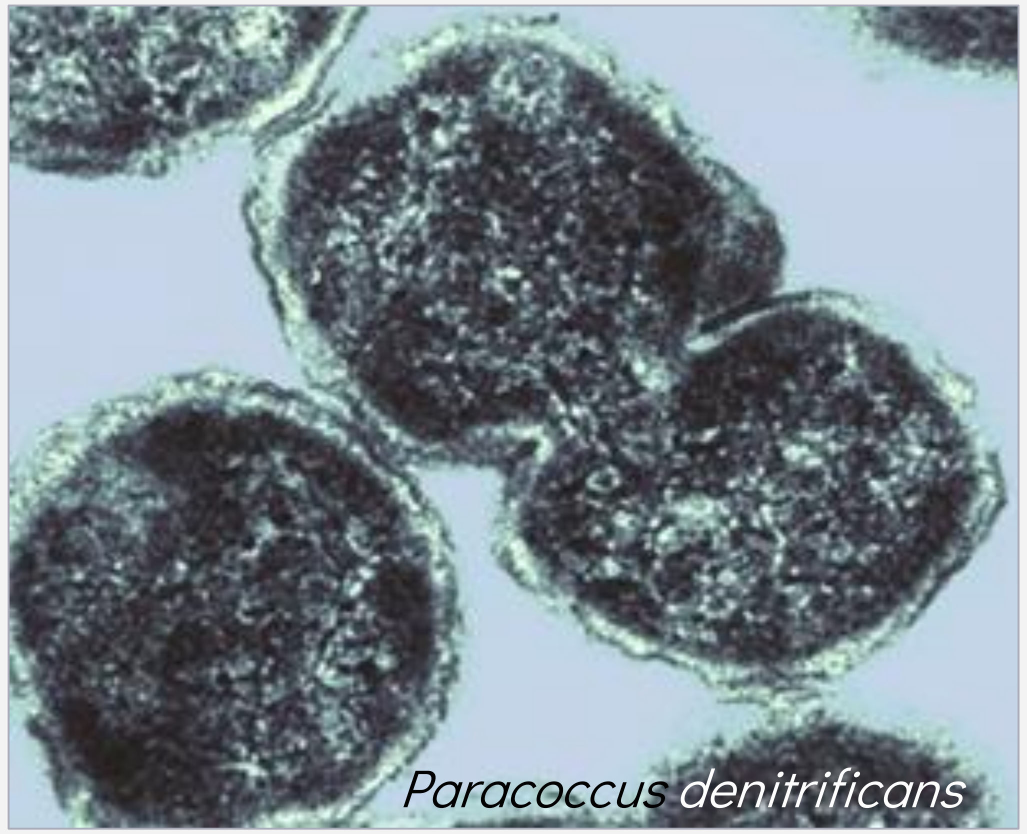
Examples of denitrifying bacteria: genera *Bacillus*, *Paracoccus*, and *Pseudomonas*; *Thiobacillus denitrificans*,, some species of *Serratia*, and *Achromobacter*.

Denitrifiers are chemoorganotrophs (must also be supplied with some form of organic carbon).

Pseudomonas stutzeri



Thiobacillus denitrificans



Paracoccus denitrificans

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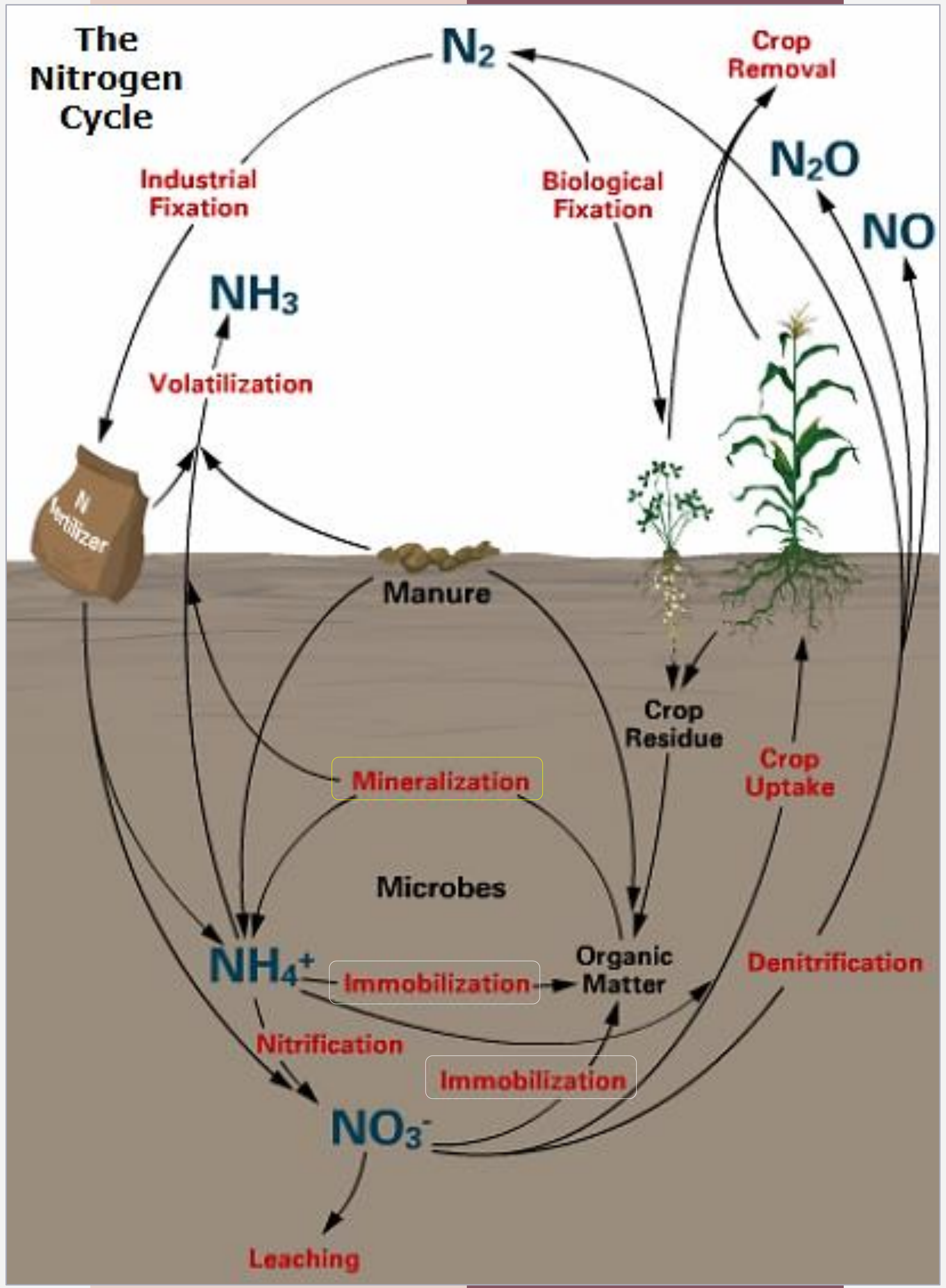


MINERALIZATION VS IMMOBILIZATION

Nitrogen mineralization:

- Decomposition of the chemical compounds in organic matter by microbes, to release the bioavailable ammonium (i.e. in ammonification).

Nitrogen immobilization:

- Nitrate and ammonium are taken up by soil microbes and become unavailable to plants.

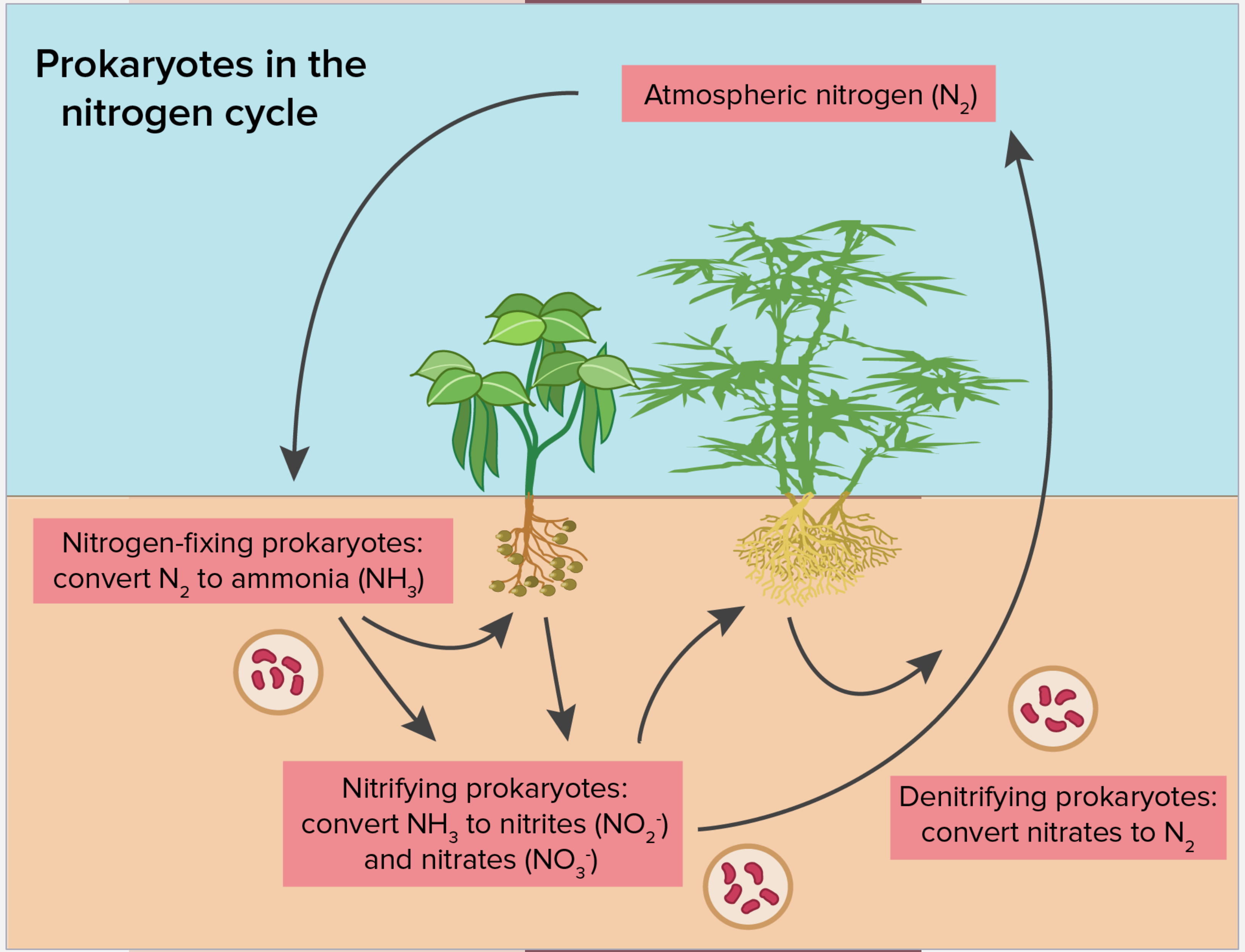
Depends on the C/N ratio of the plant residues.

- High C/N ratio → immobilization
- Low C/N ratio → mineralization

Happen continuously and concurrently.

“The nitrogen cycle”, http://cceonondaga.org/resources/nitrogen-basics-the-nitrogen-cycle, used under a Fair Use rationale.

KEY ROLES OF PROKARYOTES IN THE NITROGEN CYCLE



Converting atmospheric nitrogen into biologically usable forms.

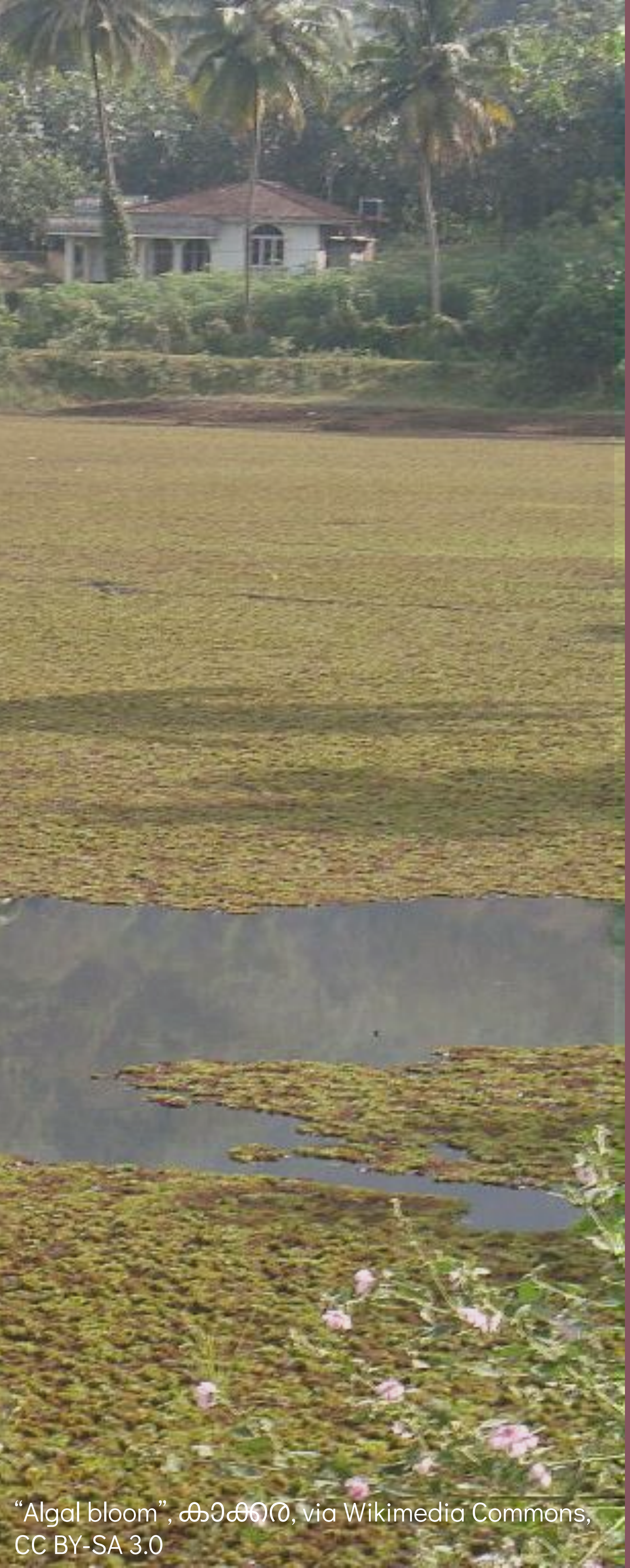
- Nitrogen fixation.

Converting ammonia to nitrites and nitrates.

- Nitrification.

Converting nitrates to nitrogen gas and release it back to the atmosphere.

- Denitrification.


"Algal bloom", കാക്കര, via Wikimedia Commons, CC BY-SA 3.0

IMPACTS OF HUMAN ACTIVITIES

Human increases in the amount of biologically available N dramatically, altering the nitrogen cycle.

- Fossil fuels burning
- Nitrogen-based fertilizers.

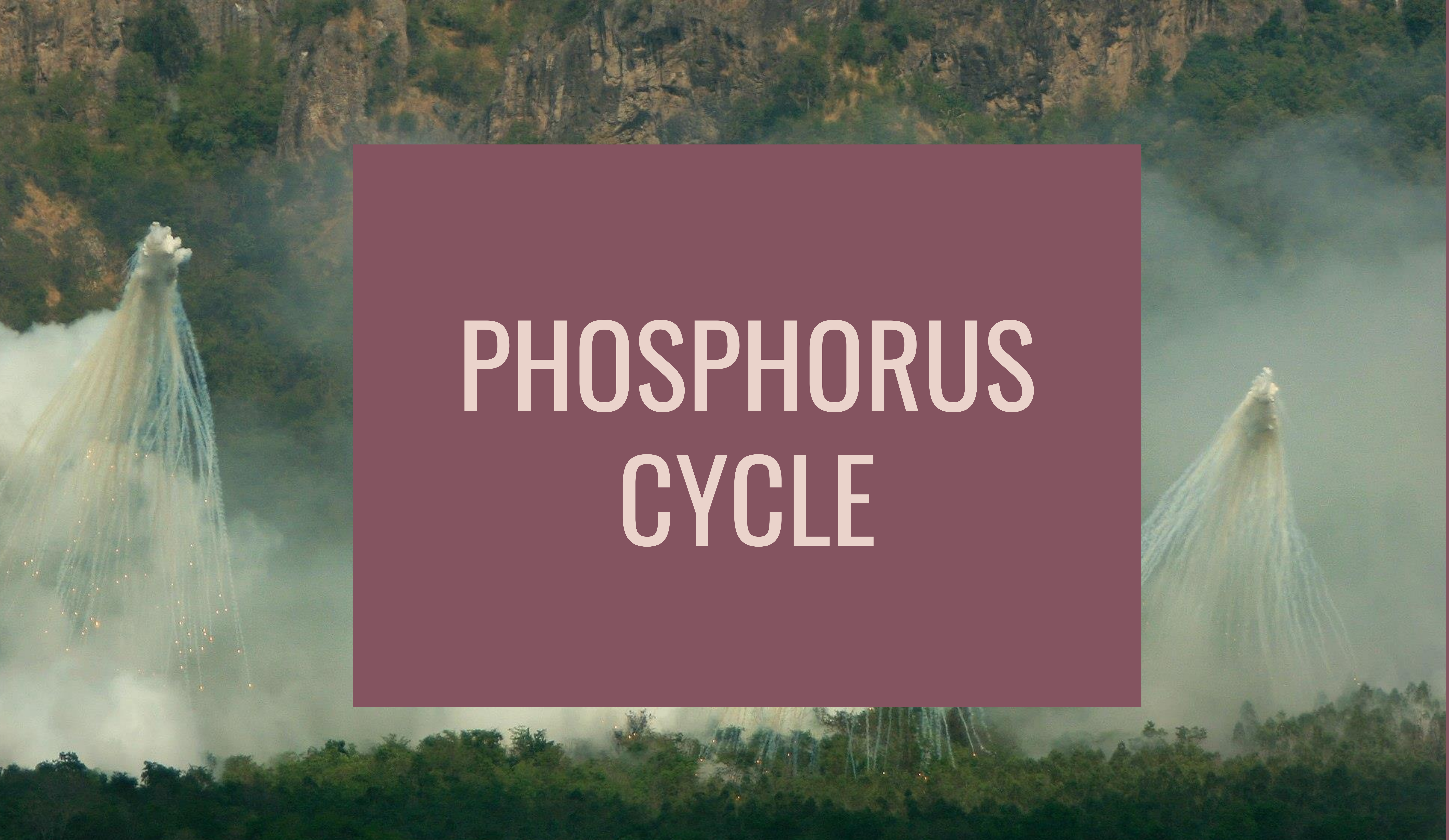
In terrestrial ecosystems:

- Nutrient imbalance in trees, changes in forest health, declines in biodiversity.

In aquatic ecosystems:

- Anoxia or hypoxia, changes in food-web structure, harmful algal blooms, acidification.

PHOSPHORUS CYCLE



IMPORTANCE OF PHOSPHORUS

An essential nutrient of both plants and animals.

- Component of DNA, RNA, ATP, proteins and enzymes.
- Forms phospholipids in plants and animal cell membranes.
- Forms bones, teeth, and shells of animals as calcium phosphate compounds.

Often acts as the limiting nutrient, especially in aquatic ecosystem.

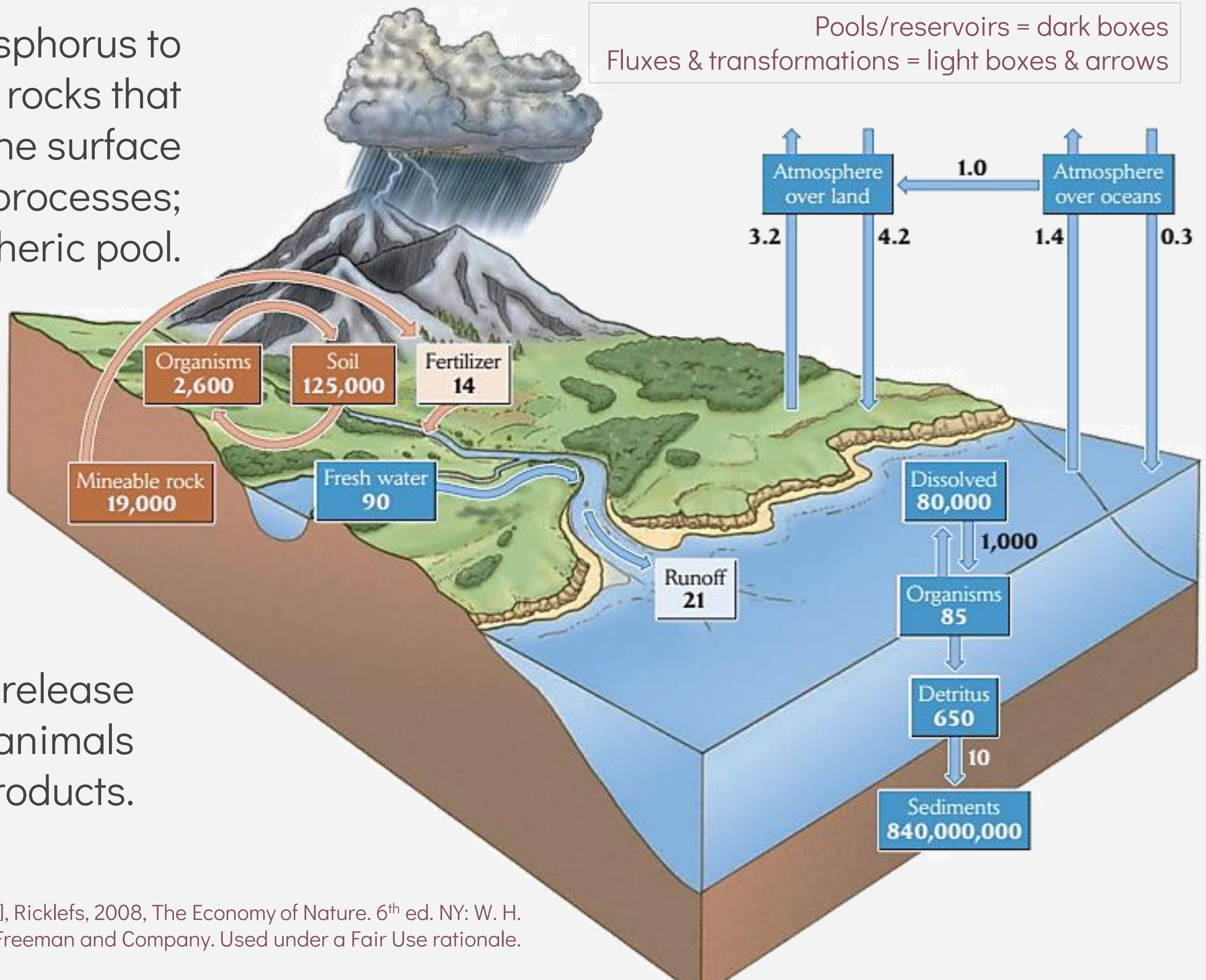
GLOBAL PHOSPHORUS CYCLE

RESERVOIR – erosion transfers phosphorus to water and soil; sediments and rocks that accumulate on ocean floors return to the surface as a result of uplifting by geological processes; no atmospheric pool.

ASSIMILATION – plants absorb inorganic PO_4^{3-} (phosphate) from soils; animals obtain organic phosphorus when they eat plants and other animals.

RELEASE – plants and animals release phosphorus when they decompose; animals excrete phosphorus in their waste products.

Pools/reservoirs = dark boxes
Fluxes & transformations = light boxes & arrows



[Figure 23.14], Ricklefs, 2008, The Economy of Nature. 6th ed. NY: W. H. Freeman and Company. Used under a Fair Use rationale.

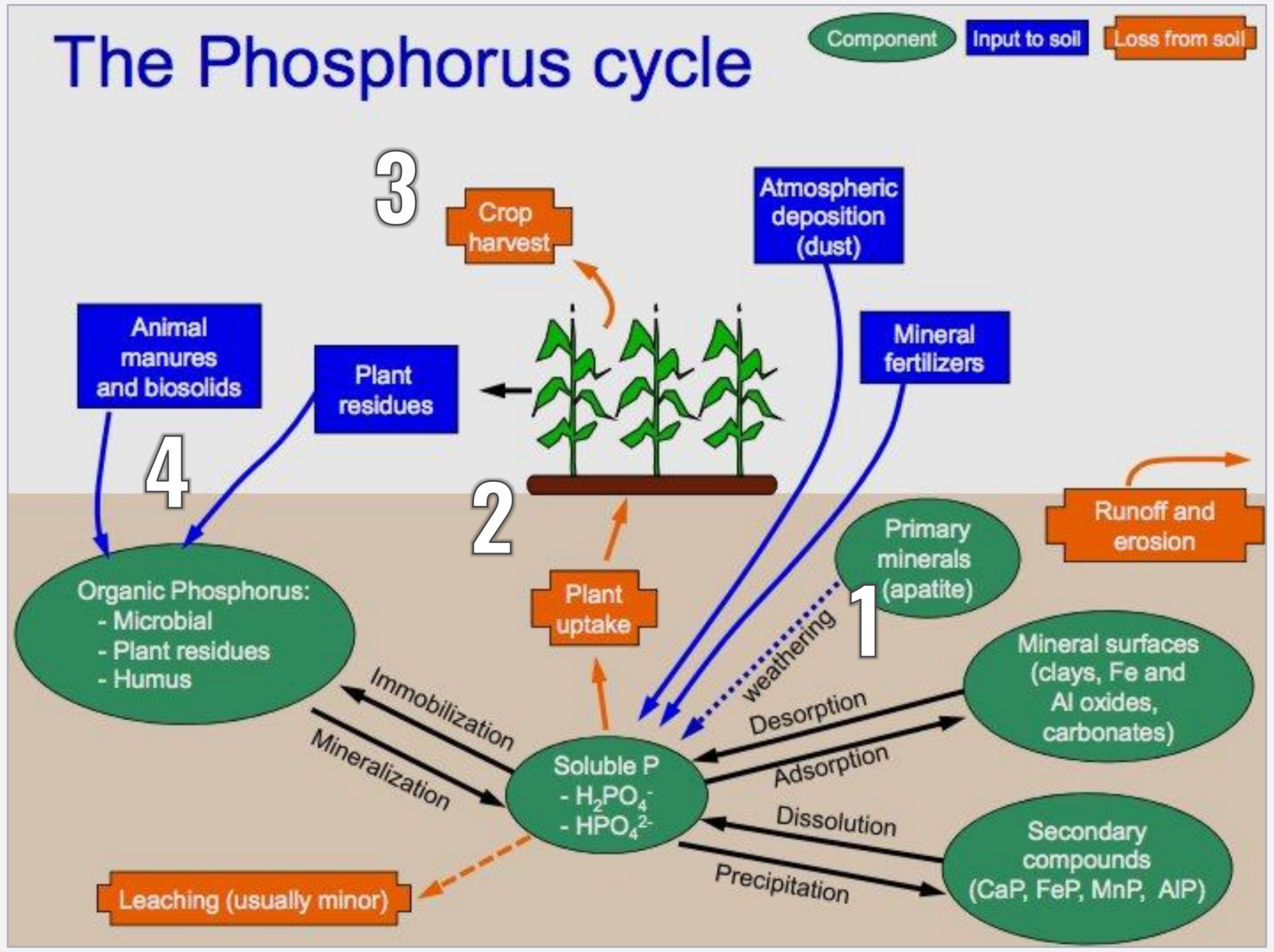
MAIN STEPS OF PHOSPHORUS CYCLE

1. Weathering

Extraction of P from the rocks by weathering.

2. P intake by plants

The available P in the soil is then taken up directly by plants or through symbiotic microorganisms.



3. Movement of P in the food chain

The P-containing organic compounds in plants are eaten by the consumers.

4. Return of P to the ecosystem

Mineralization of organic P into their inorganic forms (decomposition).

MAIN STEPS OF PHOSPHORUS CYCLE
1. WEATHERING

Rocks are one of the primary sources and reservoirs of P.

Phosphate salts are broken down from the rocks and washed away into the soil, making it bioavailable for plants.

Weathering/solubilizing agents:

- Rain.
- Acid produced by microorganisms (e.g. *Actinomycetes, Pseudomonas, Bacillus, Aspergillus, Penicillium*).

MAIN STEPS OF PHOSPHORUS CYCLE

2. PHOSPHORUS INTAKE BY PLANTS

Available P (phosphate salts) in the soil is then absorbed by plants.

Aquatic plants in oceans absorb phosphorus from the lower layers of aquatic sediments.

The level of P present in the soil is often still too low.

- Hence the need to add phosphate fertilizers on agricultural land.

MAIN STEPS OF PHOSPHORUS CYCLE

3. PHOSPHORUS MOVEMENT IN THE FOOD CHAIN

Plants uses the absorbed P to form different organic compounds.

The organic compounds then move through the food chain (consumers feed on producers).

The organic form of P undergoes changes as it moves through the consumers.

The rate of the P cycle is faster in plants and animals than in rock.

MAIN STEPS OF PHOSPHORUS CYCLE

4. RETURN OF PHOSPHORUS TO THE ECOSYSTEM

P in organisms can be transferred back to the reservoir through decomposition (mineralization).

P in the soil is also transported to the ocean by rainfall or surface runoff.

P in the ocean undergoes deposition, forming layers of sediments, eventually forming rocks, and the cycle continues.

IMPACTS OF HUMAN ACTIVITIES

Phosphate rock mining for fertilizers and detergents.

Anthropogenic eutrophication.

- Algal bloom are toxic to the plants and animals in the ecosystem.

Deforestation reduces P ability to replenish.

“Phosphate mining area in Morocco (Bouazzer)”, jbdodane, https://flic.kr/p/dYkgXt, CC BY-NC 2.0.

SULFUR CYCLE

IMPORTANCE OF SULFUR

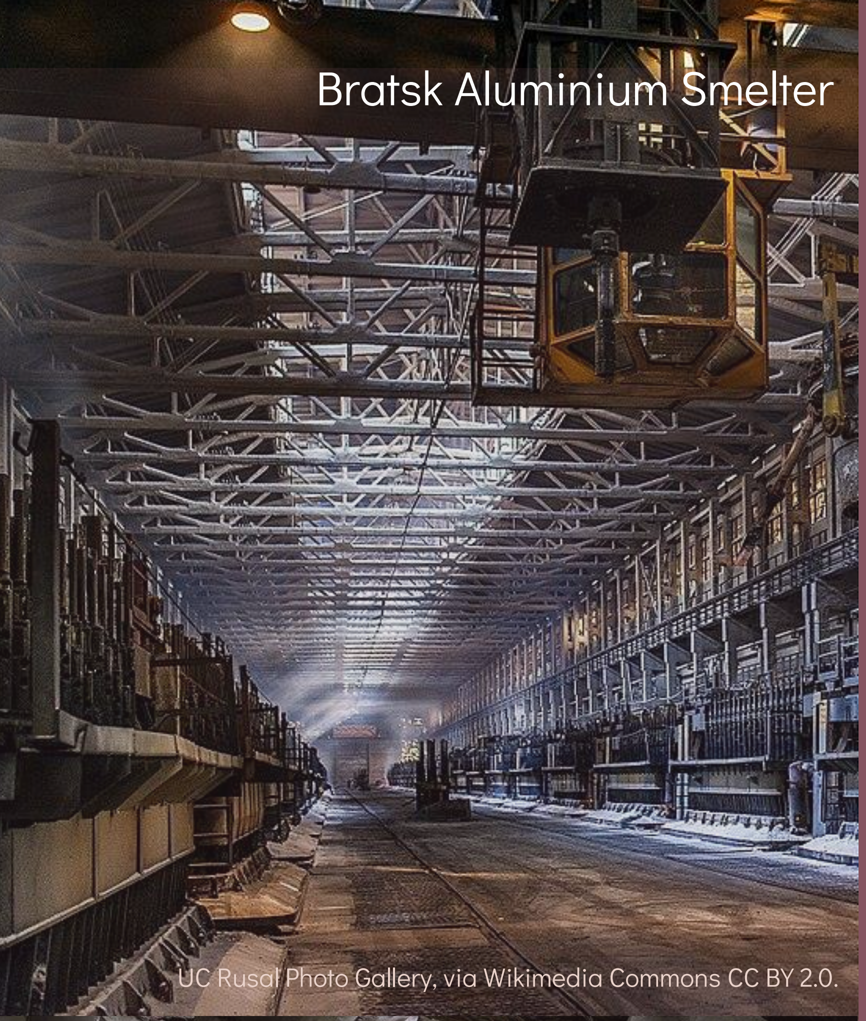
A component of protein and enzyme system.

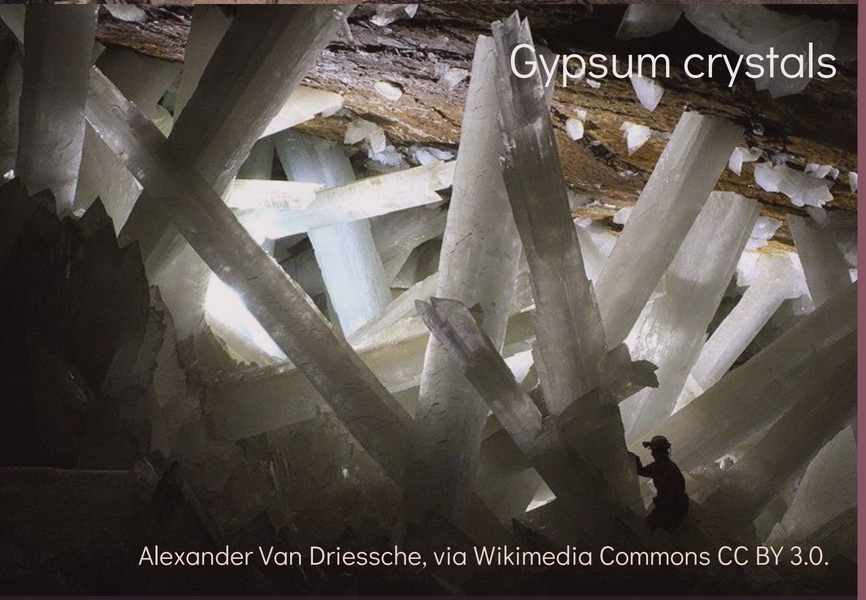
A macronutrient required by plants.

Many animals & humans depend on plants for S-containing amino acids.

Important in plants defense system.

- Sulfur metabolites (e.g. glutathione) protects against oxidative stress, heavy metals, and xenobiotics.


Bratsk Aluminium Smelter


Gypsum crystals


Pyrite

NATURAL SOURCES OF SULFUR

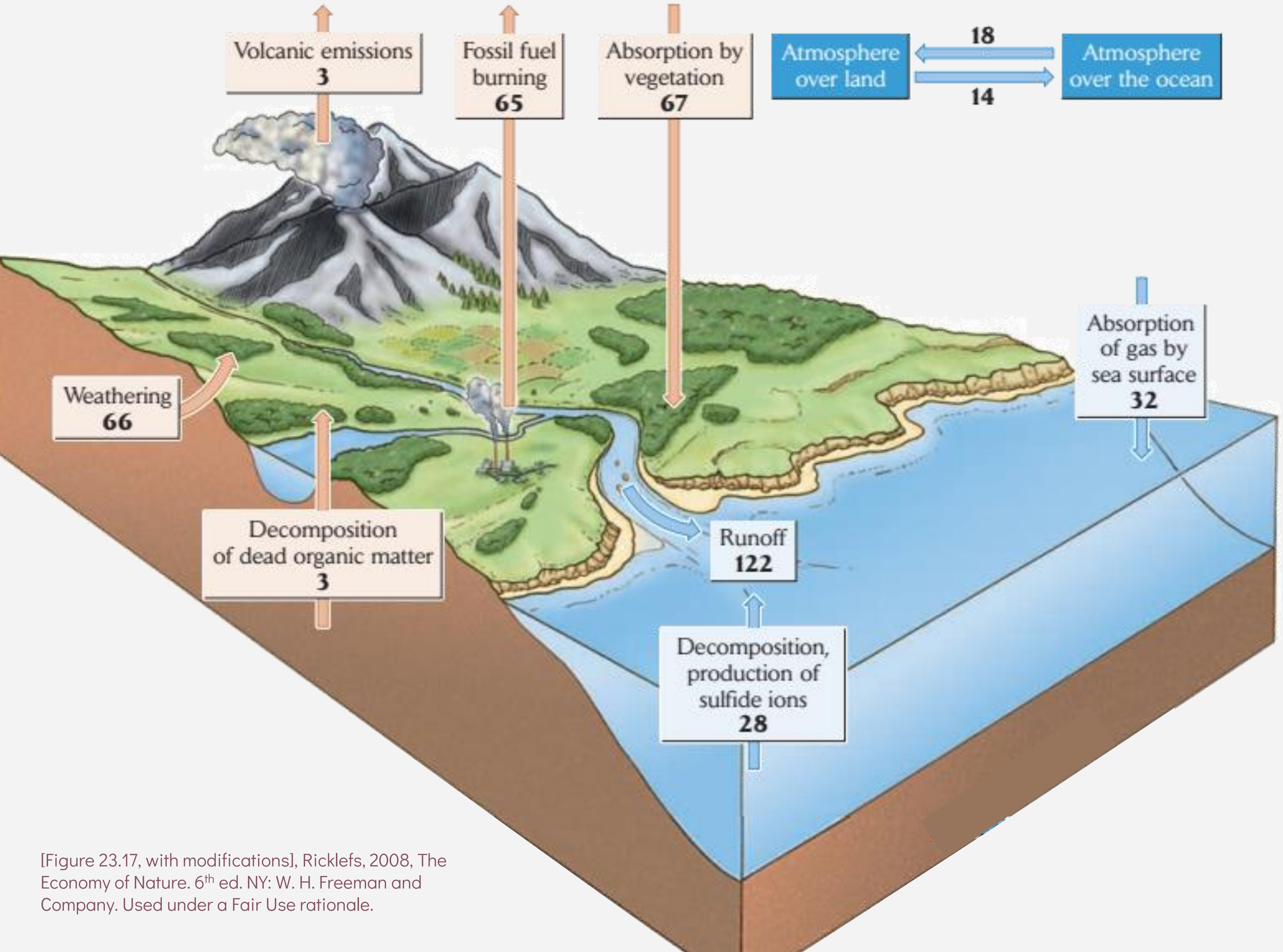
Natural sources

- Elemental sulfur in volcanoes and hydrothermal vents.
- Sulfide minerals, e.g. pyrite, cinnabar, sphalerite.
- Sulfate minerals, e.g. gypsum, barite.

Anthropogenic sources

- Fossil fuel combustion at power plants, and other industrial facilities.
- Burning of high sulfur fuel in vehicles.
- Ore smelters.

GLOBAL SULFUR CYCLE



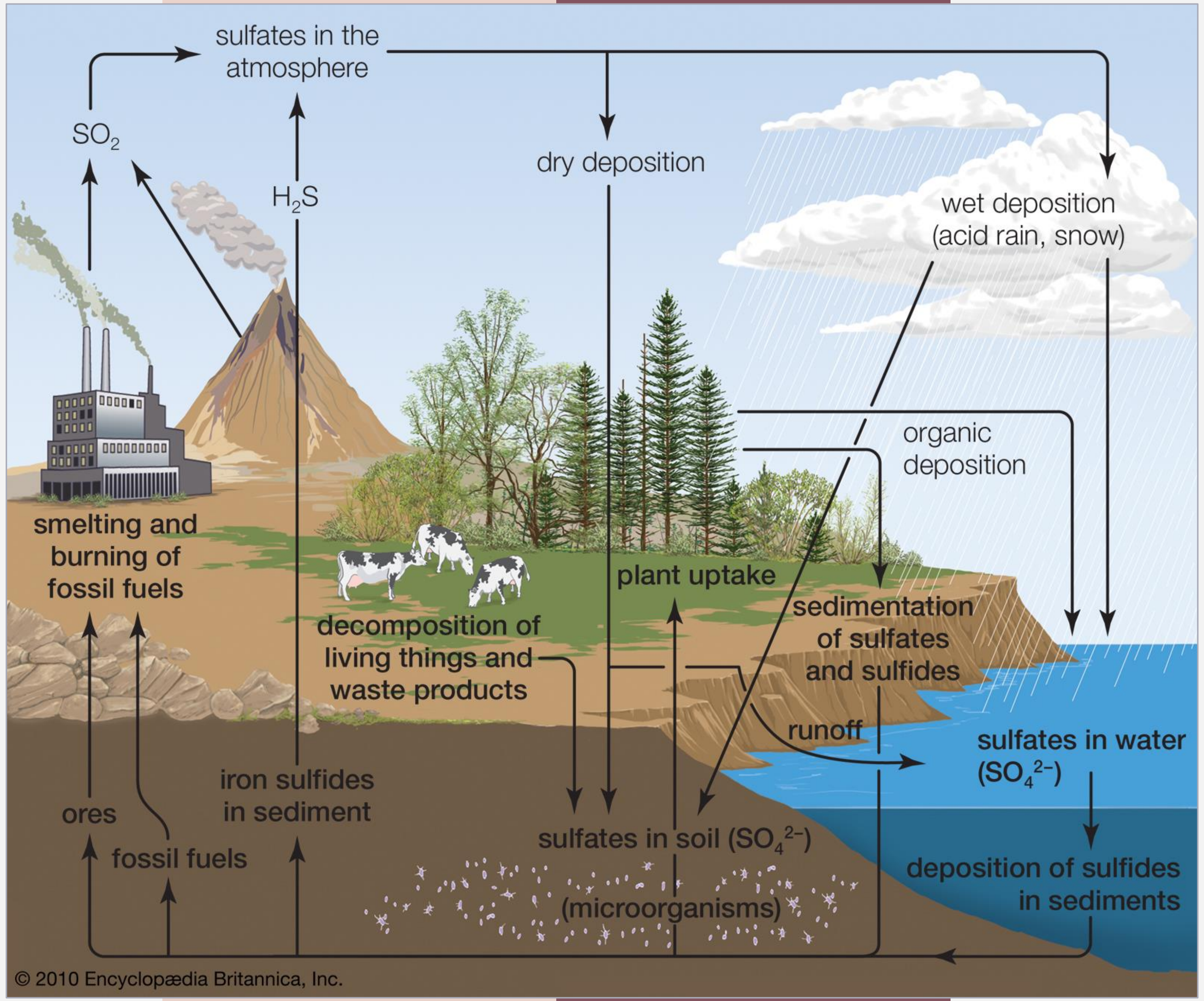
[Figure 23.17, with modifications], Ricklefs, 2008, The Economy of Nature. 6th ed. NY: W. H. Freeman and Company. Used under a Fair Use rationale.

RESERVOIR – largest: marine sediments and evaporate deposits (pyrite and gypsum), the ocean, the ocean floor basalts; smaller: the atmosphere, rivers & lakes, biomass, soils, aquifers.

ASSIMILATION – plant absorb inorganic sulfate from soils, assimilate it into cysteine and various S-containing secondary metabolites; animals obtain organic sulfur from consuming plants.

RELEASE – plants and animals release sulfur when they decompose.

STEPS IN SULFUR TRANSFORMATIONS



"Sulfur cycle", Encyclopædia Britannica, used under a Fair Use rationale

1. Mineralization of organic sulfur into inorganic forms, (e.g. H_2S, elemental sulfur, sulfide minerals).
2. Oxidation of H_2S and elemental sulfur (S) to sulfate (SO_4^{2-}).
3. Reduction of sulfate to sulfide (S^{2-}).
4. Incorporation of sulfide into organic compounds (organosulfur).

IMPACTS OF HUMAN ACTIVITIES

Human activities alter the balance of the global sulfur cycle.

A large part of sulfur emissions are of anthropogenic sources.

- Fossil fuel combustion in vehicles, smelters, industrial processes.

Acid deposition.

- Lowering the pH of lakes, killing the fauna.
- Causing a chemical degradation of buildings.
- Causing the destruction of forest.

[Forest dieback in the Bavaria Forest], High Contrast, via Wikimedia Commons, CC BY 3.0 DE.

[Acid rain results on monuments], Nino Barbieri, via Wikimedia Commons, CC BY-SA 3.0.

OXYGEN CYCLE

SOURCES OF OXYGEN

Second most abundant elements in the atmosphere.

Main sources:

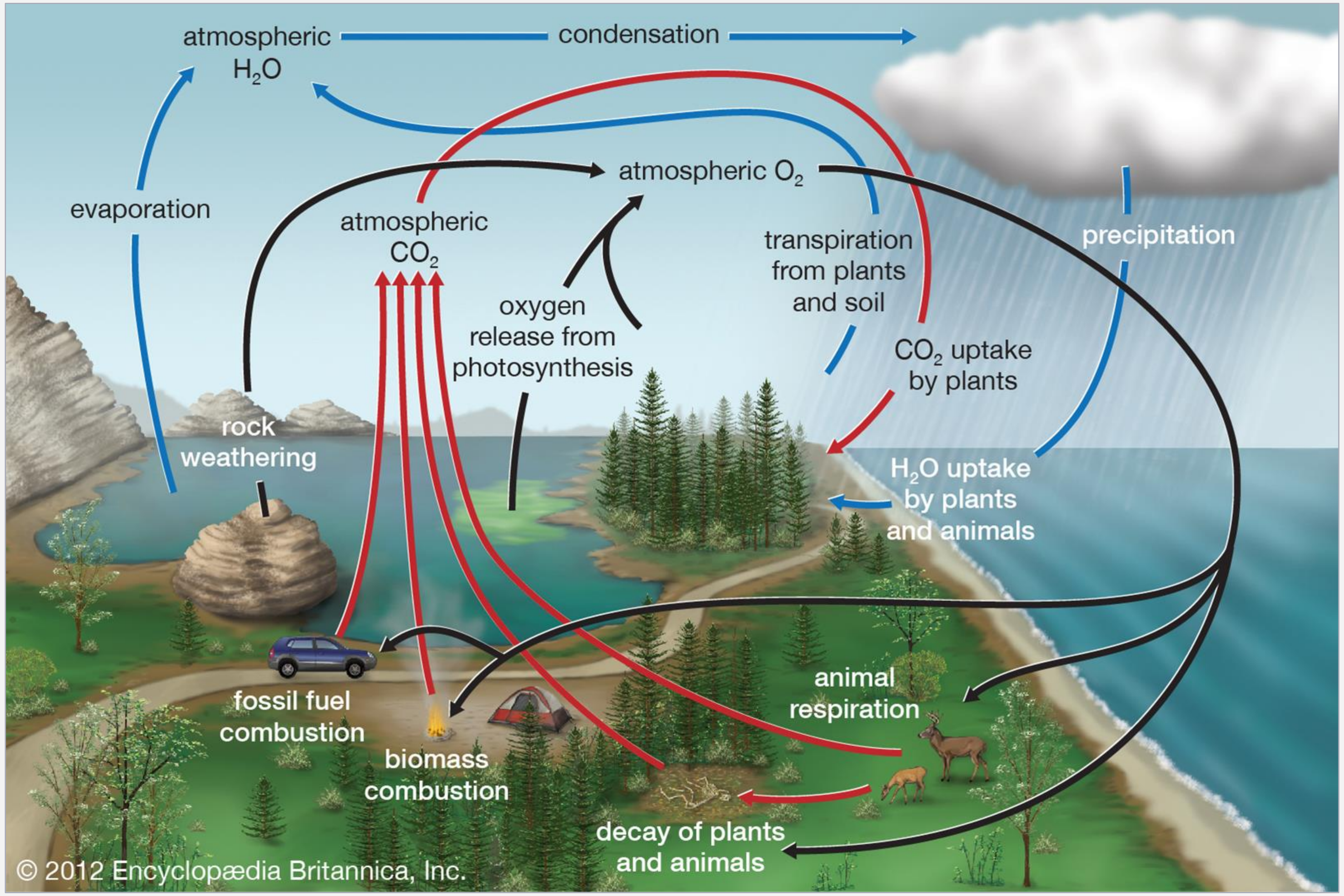
- Photosynthesis (phytoplankton and green plants).
- Photolysis (disassociation of water vapor by uV light).

GLOBAL OXYGEN CYCLE

RESERVOIR – largest: silicate and oxide minerals of the Earth's crust and mantle; the remaining is contained in the atmosphere, hydrosphere, and biosphere.

ASSIMILATION – photosynthesis, respiration by heterotrophs.

RELEASE – respiration and decomposition.



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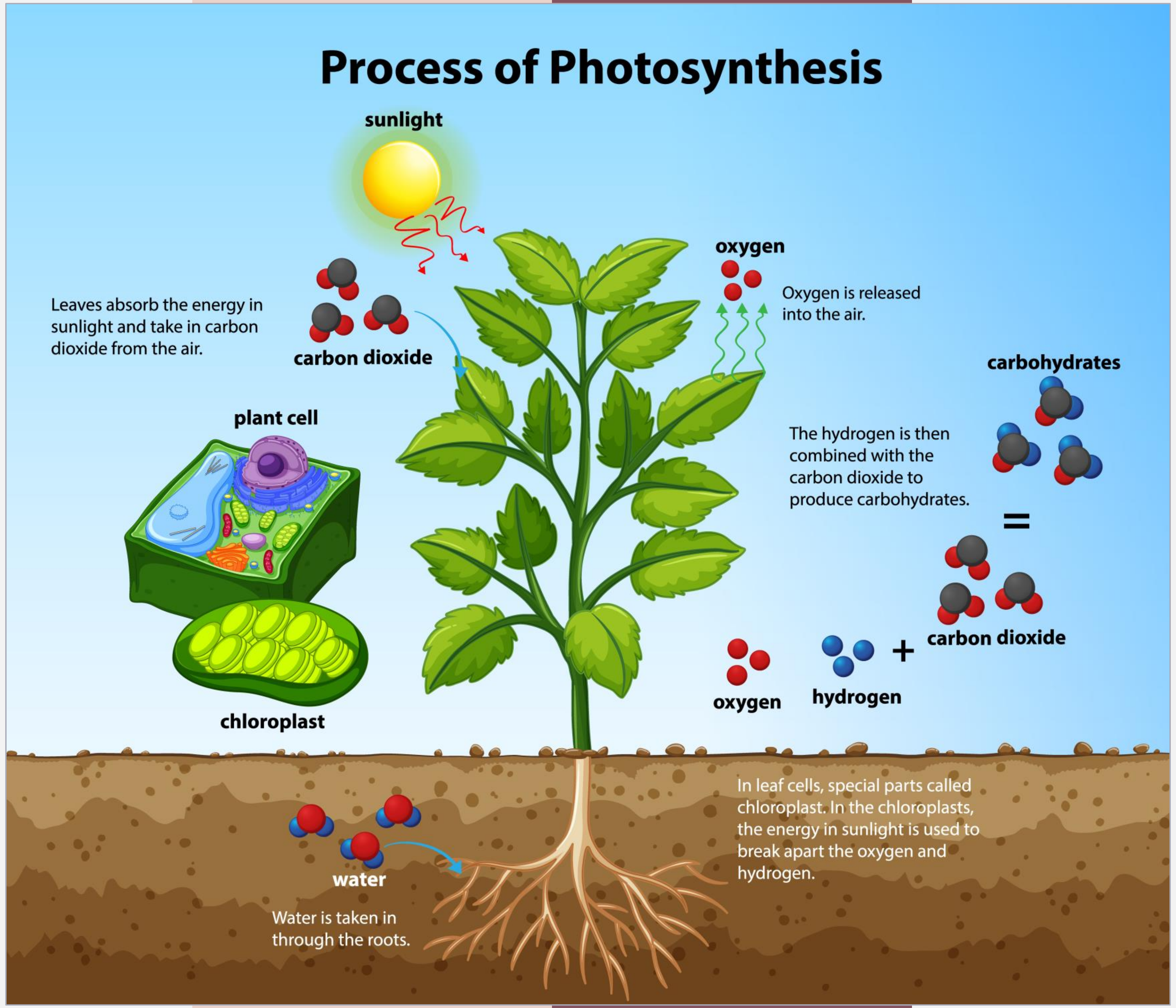


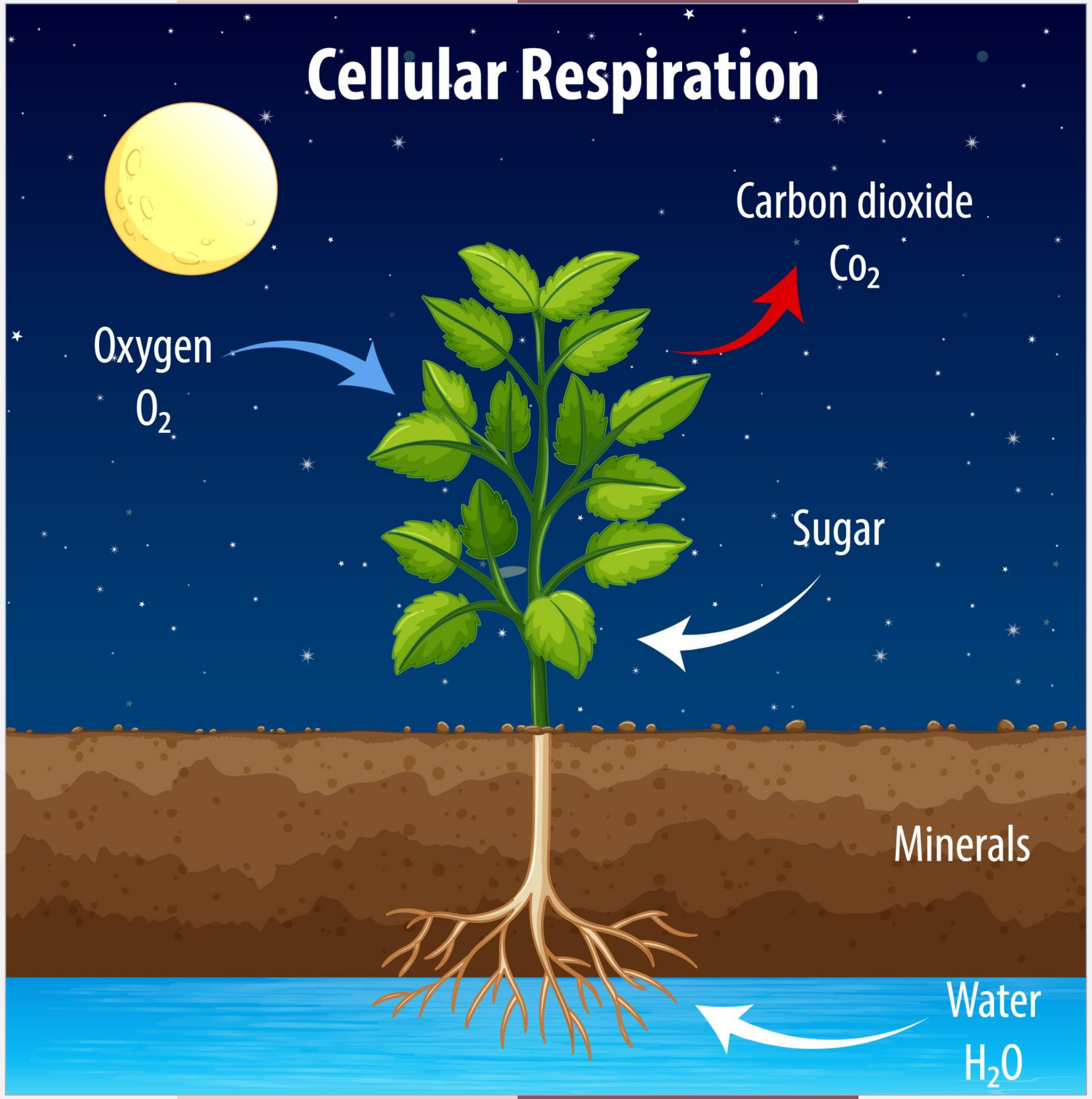
"Photosynthesis", brgfx via www. Freepik.com, Freepik license.

The process by which plants create oxygen and energy from sunlight, water, and carbon dioxide

Main source of atmospheric free oxygen.

$$6\,CO_2 + 6\,H_2O + energy \rightarrow C_6H_{12}O_6 + 6\,O_2$$

Linking various oxygen reservoirs.



"Cellular respiration", brgfx via www. Freepik.com, Freepik license.

CELLULAR RESPIRATION

A process combining oxygen with food molecules, converting chemical energy from oxygen molecules into ATP, and discarding waste products (water and CO_2).

$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6\,CO_2 + 6\,H_2O + energy$$

The main way free oxygen is lost from the atmosphere.

ROLES OF OZONE (O_3)

An ambivalent atmospheric gas.

In the stratosphere:

- Protects Earth from uV radiation.

In the troposphere:

- A damaging pollutant (smog), irritating eyes and respiratory systems, injuring/killing plant life.

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